VOL. 29, NO. 2 JUNE 1956

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

PUBLISHED BIMONTHLY BY THE BUREAU OF PUBLIC ROADS, U. S. DEPARTMENT OF COMMERCE, WASHINGTON

In this issue: A study of service lives of highway surfaces. How long will a surface remain in use before it is resurfaced, reconstructed, or otherwise replaced?

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Published Bimonthly

Vol. 29, No. 2 *June 1956*

C. M. Billingsley, *Editor*

IN THIS ISSUE

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The printing of this publication has been approved by the Director of the Bureau of the Budget, Mar. 17, 1955.

Lives of Highway Surfaces—Half Century Trends

BY THE FINANCIAL AND ADMINISTRATIVE RESEARCH BRANCH BUREAU OF PUBLIC ROADS

Reported [1] by GORDON D. GRONBERG, Head, Annual Cost Unit, and NELLIE B. BLOSSER, Statistician

That highways do wear out is an accepted fact. Since World War II our construction program has been greatly expanded. What influence has this stepped-up program had on the service lives of our roads? Are the miles of roads actually retired greater or lesser than those developed in past estimates? This article attests to the validity of previous estimates and adds 7 years experience to the information presented in an earlier article.

Among the major objectives of the road-life study phase of the highway planning surveys is the development of factual data relating to (1) how long road surfaces remain in service before they are replaced, and (2) what is done to the road surfaces at the time of replacement. This is the third article presented on this subject in the past 16 years. The first article was published in 1941 and the second in 1949.

In the present article the life experience of road surfaces on primary rural highways covers the period from January 1, 1900, to January 1, 1953. The basic data were submitted by 25 States and Puerto Rico for rural State or Federal-aid primary systems and include 344,108 miles of construction and 192,741 miles of retirements. Results of the analysis show that the number of years a surface remains in service before it is resurfaced, reconstructed, or otherwise replaced ranges from 5.2 years for lower type surfaces to 25.5 years for the higher type surfaces.

Of the 183,976 miles analyzed by method of retirement through 1952, 57 percent were resurfaced, 31 percent reconstructed, 9 percent transferred to other public agencies, and 3 percent abandoned. Since the end of World War II the proportion resurfaced has decreased and the proportion reconstructed has increased.

Data for nine States are common to all three articles. For these nine States, an estimate was made of mileages that would still be in service in 1953 if road surfaces continued to be retired at the rates shown in the 1941 and 1949 studies. This estimate was then checked against the actual mileages remaining in 1953. There was close agreement between the actual and estimated miles remaining. The differences between the previous forecasts and the present study may be partly due to the lagging highway program during the war and postwar periods.

The service life data developed in this article were used in estimating the probable mileages remaining in service in future years. During the 10 years, January 1, 1953, to January 1, 1963, it is estimated that 96 percent of the low-type, 83 percent of the intermediate-type, and 61 percent of the high-type surfaces in service at the beginning of the period will be retired through resurfacing, reconstruction, abandonment, or transfer.

THE highway systems of the Nation are a vital segment of our national economy. The proper management of these systems and the protection of the investment they represent require detailed knowledge of their performance. Many facts are needed with respect to their construction, maintenance, operation, and administration. To supply these facts is one function of the highway planning surveys which were established in the middle 1930's by the State highway departments in cooperation with the Bureau of Public Roads.

Despite their extent and advanced stage of development most of our highways are inadequate for the demands of present day traffic. Much of the current inadequacy dates to World War II when highway construction was cut to a minimum as a result of the defense effort. Highways were kept in operating condition with a minimum of expenditure to conserve labor, equipment, and materials. At the end of World War II an out-dated highway system was called upon to handle heavier traffic demands than ever before. To solve the problem, many States undertook highway needs studies. Attention was directed to both long- and short-range planning.

Funds were limited and progress was slow. In the meantime, the needs continued to mount. There was need for current information relating to the performance of roads; that is, how fast they were wearing out and how long they would remain in service. The proper evaluation of these data is necessary to determine the dimensions of future needs. The data necessary for these evaluations are obtained from the road life studies of the highway planning surveys. Included are such items as rates of wearing out, construction cost, maintenance cost, extent of functional obsolescence and structural deterioration, and life of the investment. The findings must be appraised in the light of changing traffic volumes, heavier loads, and higher speeds.

One of the objectives of road life studies in the individual States is the development of an organized body of information concerning life characteristics of highway surfaces. The first comprehensive analysis of such data was published in 1941.[2] In that article (hereafter referred to as the 1941 article or study) were included the results of service-life analyses on 210,000 miles of construction up to January 1, 1937, for various surface types in 26 States.

There was little activity in the road life studies from 1940 through World War II. However, most States resumed operations once the war was over and a second article on service lives of roads in 16 States was published in 1949.[3] Included in the study (hereafter referred to as the 1949 article or study) were the service-life analyses on 248,783 miles of construction and 129,593 miles of retirements up to January 1, 1946.

In the present article, data for 25 States and Puerto Rico (see fig. 1) are included:

Arizona	Nevada
California	New Mexico
Connecticut	Oklahoma
Delaware	Pennsylvania
Florida	Rhode Island
Georgia	South Dakota
Illinois	Tennessee
Indiana	Texas
Kansas	Washington
Minnesota	West Virginia
Mississippi	Wisconsin
Missouri	Wyoming
Montana	Puerto Rico

Nine of these States were also included in the 1941 and the 1949 articles: Indiana, Kansas, Missouri, Montana, New Mexico, Oklahoma, Texas, West Virginia, and Wyoming. In addition to the nine States, the

[1] This article was presented at the 35th Annual Meeting of the Highway Research Board, Wash., D. C., Jan. 1956.

[2] *Life characteristics of surfaces constructed on primary rural highways*, by Robley Winfrey and Fred B. Farrell. PUBLIC ROADS, vol. 22, No. 1, Mar. 1941; also Proceedings of the Highway Research Board, vol. 20, 1940, pp. 165–199.

[3] *Life characteristics of highway surfaces*, by Fred B. Farrell and Henry R. Paterick. PUBLIC ROADS, vol. 25, No. 9, Aug. 1949; also Proceedings of the Highway Research Board, vol. 28, 1948, pp. 40–52.

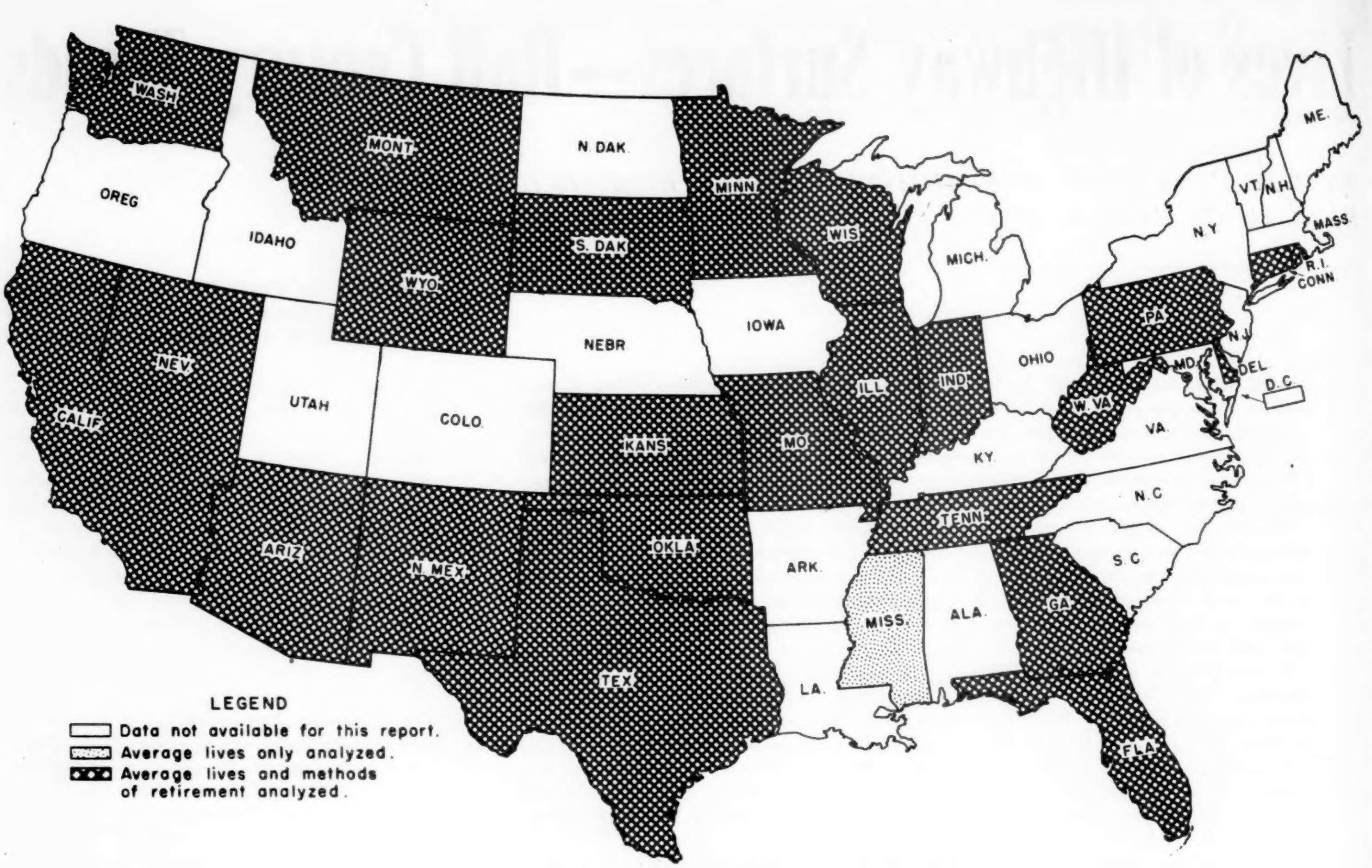

Figure 1.—States for which road-life mileage data are included.

present article includes four States listed in the 1949 study: Illinois, Minnesota, Nevada, and Wisconsin.

Basic Data Compiled

This article embraces 344,108 miles of construction of various surface types on the rural portions of the primary State or Federal-aid systems for 25 States and Puerto Rico. In general, all mileage in incorporated places of more than 1,000 persons has been excluded. Construction involving widening of roadways has also been omitted in those cases where the widening was done as a separate operation. Where the widening was done in conjunction with the resurfacing or reconstruction of the previous surface, the mileage of the new construction, which includes widening, is represented in the tabulations. The basic tables 1 and 4 cover the period from January 1, 1900, to January 1, 1953, and summarize the following information:

1. Mileage constructed each year for each surface type (for 25 States and Puerto Rico).
2. Mileage of each year's construction of each surface type remaining in service on January 1 of each year after construction (for 25 States and Puerto Rico).
3. Method of retirement (resurfaced, reconstructed, abandoned, or transferred) for mileage of each surface type retired each year (24 States and Puerto Rico).

Data for Mississippi were not available for the summaries prepared in connection with item 3. Information for California is for Federal-aid routes numbered 1, 2, 3, 7, and 8 and for Montana, U. S. Route 10 only.

There are eight major surface types for which individual service-life analyses were made: soil-surfaced, gravel or stone, bituminous surface-treated, mixed bituminous, bituminous penetration, bituminous concrete, portland cement concrete, and brick or block.

Definitions of these surface types, used in all phases of the highway planning surveys in determining the general type classifications constructed in the individual States, are found in the appendix (pp. 23–24). Definitions of the four methods of retirement are also included in the appendix.

Average Life Defined

The average service life of a road surface is the average period of time after construction that the surface remains in service prior to being replaced, resurfaced, reconstructed, or otherwise taken out of service for any reason or by any method. Stated in another manner, it is that period of time after construction during which the only operations performed on the road surface are those of maintenance as practiced by the various States.

It is a recognized fact, however, that a significant amount of construction work is done with maintenance funds in many States. This is particularly true in the low and intermediate surface types. In recording the original data summarized in this study, an attempt was made in each State to segregate construction from maintenance in a uniform manner regardless of the particular accounting practices in effect in a given State. The classifications of construction and maintenance operations generally followed in the road life study are those included in the tentative draft of the report to the 1938 meeting of the Subcommittee on Uniform Accounting of the American Association of State Highway Officials.[4]

Analysis Procedures

Survivor curve analysis procedures employed are substantially the same as those discussed at some length in the 1941 article. Reference should be made to this earlier study for an explanation of the mechanics for computing average service life. In the 1941 study, a single analysis was made of combined data for all States while in the 1949 study and the present one, individual analyses were made for each State and the results combined by weighting. The two procedures will yield the same results. One of the advantages of analyzing the data by individual States is that results are retained for each State and are available for use in further State studies.

The average life data included in this article represent estimates based on actual experience. Over the years there have been changes

[4] Copies of this tentative draft were transmitted to all State highway departments under date of June 2, 1938, by the Subcommittee on Uniform Accounting, American Association of State Highway Officials.

Table 1.—Mileages constructed and mileages remaining in service on January 1, 1953, for each surface type [1]

Construction-year period	Soil-surfaced		Gravel or stone		Bituminous surface-treated		Mixed bituminous		Bituminous penetration		Bituminous concrete		Portland cement concrete		Brick or block	
	Miles constructed	Miles remaining in service	Miles constructed	Miles remaining in service	Miles constructed	Miles remaining in service	Miles constructed	Miles remaining in service	Miles constructed	Miles remaining in service	Miles constructed	Miles remaining in service	Miles constructed	Miles remaining in service	Miles constructed	Miles remaining in service
1920 and prior	488.1	6.2	10,713.6	11.5	2,864.4	596.0	64.0	6.9	533.9	118.5	814.7	115.5	2,826.1	489.6	728.5	87.3
1921–25	1,165.9	5.5	22,493.4	421.5	3,665.1	896.8	317.7	43.2	2,454.8	517.8	1,510.6	295.9	12,169.1	5,119.9	598.1	59.1
1926–30	712.6	------	24,048.3	1,360.7	8,662.1	2,464.1	6,015.9	908.4	2,251.6	663.2	2,035.9	444.3	16,909.5	11,425.9	183.0	46.5
1931–35	1,307.3	33.2	17,912.8	1,433.3	11,056.7	2,982.0	20,540.3	6,450.0	3,366.9	1,864.2	2,011.5	790.5	12,938.0	10,691.3	183.8	54.9
1936–40	1,325.4	52.9	10,136.2	804.9	12,945.1	5,695.9	17,157.0	9,498.1	2,726.2	2,142.9	4,256.9	2,574.7	6,962.5	6,114.5	49.6	27.5
1941–45	448.0	18.1	4,688.4	730.8	7,682.7	4,616.9	7,917.5	5,129.1	1,967.6	1,516.5	4,543.6	3,537.0	2,489.5	2,299.5	14.5	7.9
1946–50	276.0	25.6	5,716.8	1,537.8	10,623.5	9,072.5	13,882.1	12,203.4	959.6	815.3	10,081.8	9,685.3	2,982.0	2,963.4	6.1	1.7
1951–52	74.4	45.7	1,940.5	1,375.9	4,193.9	4,078.6	6,394.8	6,302.1	300.9	296.4	6,639.0	6,622.9	1,180.0	1,168.1	1.4	1.4
Total	5,797.7	187.2	97,650.0	7,676.4	61,693.5	30,402.8	72,289.3	40,541.2	14,561.5	7,934.8	31,894.0	24,066.1	58,456.7	40,272.2	1,765.0	286.3

[1] Compiled from data submitted by 25 States and Puerto Rico for rural State or Federal-aid primary systems.

in construction methods and design standards. There have been periods of accelerated activity and periods when little or no construction was accomplished. Some roads have been kept in service too long, while others have been rebuilt before the end of their useful life. Maintenance has frequently been inadequate. There have been instances of over- and under-designing. Throughout the past 35 years, nevertheless, there have been sustained improvements in the standards of highway design, construction, maintenance, and administration. Each of these factors has its influence upon service life, but individual effects cannot be evaluated with certainty. As a result of improvements which are continuously being made in design standards, for example, such factors as excessive grades, sharp curves, narrow roadway widths, and restricted sight distances formerly contributing to early obsolescence or structural failure are gradually being reduced to a minimum, or even eliminated.

The large backlog of needed replacements of highway facilities, which had accumulated during World War II, was mentioned in the 1949 study. An adjustment was made in analysis procedures on the assumption that there would be a somewhat higher than average rate of retirement for about 10 years after the war. Actual experience shows that for the first 7 years of the 10-year period, replacement rates have not been quite as high as predicted. However, State highway needs studies which are underway or have been completed show that deficiencies exist in amounts sufficient to warrant continuation of this assumption. In fact, if the accumulated deficiencies in the highway plant are to be overcome at the rates recommended in some of these long-range studies, it is likely that the probable remaining service lives may, in some instances, prove to be somewhat less than indicated by the data presented in this article.

Factors Influencing Results

In actual practice only a small percentage of road sections have a life exactly equal to the average. Thus, in estimating service life for a particular road section, it is necessary to consider such factors as age, structural condition, design features, location, and traffic usage which reflect conditions peculiar to that section. Only by the exercise of expert engineering judgment in the evaluation of these factors is it possible to arrive at an estimate of the remaining service life for a particular road section.

There are many factors that have impact on construction practice and in turn influence the trend of age of road surfaces and of expected service. These include administrative policy, availability of materials and manpower, change or influence of politics, increased activity due to State legislative action, construction activity in neighboring States and in other fields of construction, civil defense activity, and any unusual or extended nationwide highway program.

Limitations in a study such as this are understandable as data were submitted by 26 different reporting units. Each State has slightly different practices with respect to constructing and maintaining roads and in reporting data. These factors, in addition to those mentioned in the preceding paragraph, tend to have their influence on service lives, age and expectancy, methods of retirement, and so forth. Even with such limitations the findings are useful. Comparisons can be made, and the range of speculation on trends or unusual changes with respect to road-surface lives can be narrowed.

Mileage In Service

Table 1 shows for each surface type, by construction periods, the mileage constructed during each period, and the mileage remaining in service on January 1, 1953. Approximately 42 percent of the surfaced mileage on the primary rural State highway systems of the United States is represented. The proportions of each surface type included in this study are as follows:

	Percent
Soil-surfaced	5
Gravel or stone	20
Bituminous surface-treated	36
Mixed bituminous	43
Bituminous penetration	37
Bituminous concrete	50
Portland cement concrete	58
Brick or block	48
Average, all types	42

There are some mileages, particularly of the lower-type surfaces, for which the dates of retirement are known but initial construction dates are not available. This results primarily from the difficulty in locating records of early construction. Partial data in those cases are not included in the analysis.

The probable average service lives for each surface type by construction periods are shown in table 2. Estimates of average lives are given in this table for all constructed mileages reported. Because of the smaller mileages involved, the retirement trends for earlier construction are frequently more erratic than the trends for the larger mileages of more recent construction. The average life estimates for this earlier construction are more reliable, however, because of the greater experience.

Table 2.—Weighted probable average service lives for various construction-year periods for each surface type [1]

Construction-year period	Soil-surfaced	Gravel or stone	Bituminous surface-treated	Mixed bituminous	Bituminous penetration	Bituminous concrete	Portland cement concrete	Brick or block
	Years	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
1905 and prior	------	15.6	34.1	------	26.4	23.5	------	40.0
1906–10	10.5	9.2	38.8	------	24.7	27.8	41.3	25.1
1911–15	5.6	15.3	19.5	16.4	24.7	21.8	18.4	21.0
1916–20	12.7	11.5	19.0	18.4	17.9	19.8	23.3	20.7
1921–25	9.1	10.0	19.1	14.2	19.0	20.3	27.0	19.6
1926–30	6.0	8.8	16.1	12.5	18.5	17.8	26.8	20.5
1931–35	4.0	7.5	11.7	13.3	18.8	16.4	25.7	16.8
1936–40	3.2	5.6	12.0	14.7	19.6	16.1	23.1	15.6
1941–45	2.3	5.6	11.1	12.2	15.4	*14.1*	*21.1*	*10.5*
1946–50	1.5	3.1	9.5	*11.7*	*12.0*	*16.8*	*24.0*	------
1951–52	2.1	2.8	*9.3*	*13.0*	*14.7*	*17.5*	*24.3*	------
Average	5.2	8.3	12.6	13.1	18.0	16.8	25.5	19.9

[1] Based on analysis of data submitted by 25 States and Puerto Rico for rural State or Federal-aid primary systems. Average lives are to the nearest 0.1 year, but they should not be presumed accurate to this extent. The averages would be affected by excluding certain States or by including additional States. The entries in italics represent composite averages developed from the projection of trends for each State. All other entries represent averages obtained from analyses of construction and retirements where the mileages involved were sufficient to give a supportable estimate.

Table 3.—Comparison of average lives presented in the 1941 and 1949 studies with those listed in the present study

Surface type	Comparison period [1]	1941 study (26 States)		1949 study (16 States)		Present study (25 States and Puerto Rico)	
		Miles constructed	Average life	Miles constructed	Average life	Miles constructed	Average life
		Miles	*Years*	*Miles*	*Years*	*Miles*	*Years*
Soil-surfaced	1931–35	[2] 2,542	[2] 5.4	668	4.5	1,307	4.0
Gravel or stone	1931–35	22,793	6.0	18,999	5.9	17,913	7.5
Bituminous surface-treated	1931–35	[2] 10,286	[2] 11.4	9,301	[3] 7.4	11,056	11.7
Mixed bituminous	1926–30	5,610	14.3	5,801	12.3	6,016	12.5
Bituminous penetration	1926–30	3,725	17.0	1,851	16.0	2,252	18.5
Bituminous concrete	1921–25	2,362	17.9	822	18.1	1,511	20.3
Portland cement concrete	1921–25	6,737	24.4	8,855	26.1	12,169	27.0
Brick or block	1921–25	980	18.2	331	20.2	598	19.6

[1] The most recent period for which data were published in the 1941 study. [2] 1931–34.
[3] Wisconsin data had a great influence on the average life for miles constructed in the 16 States. If Wisconsin data are excluded, the average life is 10.2 years.

Comparison of Three Studies

There are certain differences in the average service lives presented in the 1941 article, the 1949 article, and the present one. Table 3 shows a comparison of the average lives for various surface types for the most recent 5-year periods for which data were listed in the 1941 study. No particular significance should be attributed to the differences in average lives shown in table 3. Variations in average service lives of this magnitude are not uncommon when the analyses are based upon different groupings and numbers of States. Furthermore, unusual construction practices in one State may have considerable effect upon the average for a group of States.

As previously mentioned, there are nine States included in the present study that were likewise included in the 1941 and 1949 studies. Based upon average lives developed in these two earlier studies, the 1941 article shows that of the mileage of all types in service on January 1, 1937, only 5 percent would probably still be in service on January 1, 1953; the actual amount was 8 percent. Similarly the 1949 article shows that of the mileage of all road types in service on January 1, 1946, 32 percent would probably still be in service on January 1, 1953; the actual amount was 34 percent.

There are, of course, greater variations within the individual surface types, but in total the results of these forecasts are sufficiently accurate to warrant considerable confidence in the analysis procedures and the average lives developed. Any differences from actuality can be readily explained. In the case of the 1941 study, the influence of the World War II period could not be anticipated; and in the case of both the 1941 and 1949 studies, there was no expectation that many surfaces would be kept in service beyond their normal life even though subjected, in most cases, to greater wear than in any previous period. In the 1949 study, it was assumed that the backlog of deferred work during the war would be overcome and normal trend resumed within a maximum of 10 years after the war, and corresponding adjustments of the service life computations were made. This assumption is proving correct although a somewhat longer period than 10 years for the "catch-up" should have been used.

Classification by Retirement Method

In all but one of the States included in the average life analysis, the retired mileages for various years were reported and classified in accordance with the method by which the retirement was made. The total mileage involved was 183,976.

The methods of retirement into which these mileages were classified are as follows: resurfaced, reconstructed, abandoned, and transferred. These retirement classifications are general in character and should be so interpreted. Definitions are included in the appendix.

Reversion in type (a surface reverts to a lower type through lack of adequate maintenance) also represents a distinct method of retirement. No retirements of this classification were reported in these data.

In table 4 are shown the total mileages retired and the percentage distribution by methods of retirement. With the exception of soil-surfaced, and brick or block types, more than one-half of all the retirements have been by resurfacing.

Table 5 shows the percentage distribution of miles retired by various methods for 5-year periods (except for the earliest and most recent years). Since the war there has been a downward trend in resurfacing and an upward trend in reconstruction.

Analysis by Major Type Groups

Figures 2–5 show some of the results of the analyses presented in the preceding discussion. For purposes of simplifying these charts, the surface types have been combined into three major groups as follows:

Low type.—Includes soil-surfaced and gravel or stone roads.

Intermediate type.—Includes bituminous surface-treated, mixed bituminous (thickness of surface and base less than 7 inches), and bituminous penetration (thickness of surface and base less than 7 inches) roads.

High type.—Includes mixed bituminous (thickness of surface and base, 7 inches or more), bituminous penetration (thickness of surface and base, 7 inches or more), bituminous concrete, portland cement concrete, and brick or block roads.

Accumulated mileages constructed and remaining in service on January 1, 1953, are shown by these groupings in figure 2. Figures 2–5 show clearly that construction programs must necessarily continue after mileage has been initially improved.

Estimates of service lives based upon actual retirement experience are shown in table 2. In general, the average lives for the more recent years were assumed to remain about the same or to increase slightly in relation to

Table 4.—Retired mileages for each surface type, and percentage distribution according to method of retirement (total for 1952 and prior) [1]

Surface type	Total retired	Methods of retirement				
		Resurfaced	Reconstructed	Abandoned	Transferred	Total
	Miles	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Soil-surfaced	5,644.1	37.5	58.1	1.2	3.2	100.0
Gravel or stone	84,051.5	58.0	30.4	2.5	9.1	100.0
Bituminous surface-treated	30,518.0	53.3	36.7	2.6	7.4	100.0
Mixed bituminous	30,821.8	57.1	29.8	3.8	9.3	100.0
Bituminous penetration	6,559.0	51.8	31.4	3.6	13.2	100.0
Bituminous concrete	7,485.8	60.9	26.0	2.4	10.7	100.0
Portland cement concrete	17,427.3	66.4	21.3	2.1	10.2	100.0
Brick or block	1,468.1	45.3	44.1	1.3	9.3	100.0
Total	183,975.6	57.0	31.3	2.7	9.0	100.0

[1] Computed from data submitted by 24 States and Puerto Rico for rural State or Federal-aid primary systems.

Table 5.—Percentage retired by various methods for all surface types combined, for various periods [1]

Method of retirement	Retirement period								
	1920 and prior	1921–25	1926–30	1931–35	1936–40	1941–45	1946–50	1951–52	Total, 1952 and prior
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Resurfaced	63.5	45.3	53.0	59.7	55.5	59.5	58.6	54.1	57.0
Reconstructed	35.7	49.0	34.9	26.6	30.9	28.8	31.5	36.4	31.3
Abandoned	.4	.6	2.3	3.8	3.4	2.7	2.0	1.6	2.7
Transferred	.4	5.1	9.8	9.9	10.2	9.0	7.9	7.9	9.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Computed from data submitted by 24 States and Puerto Rico for rural State or Federal-aid primary systems.

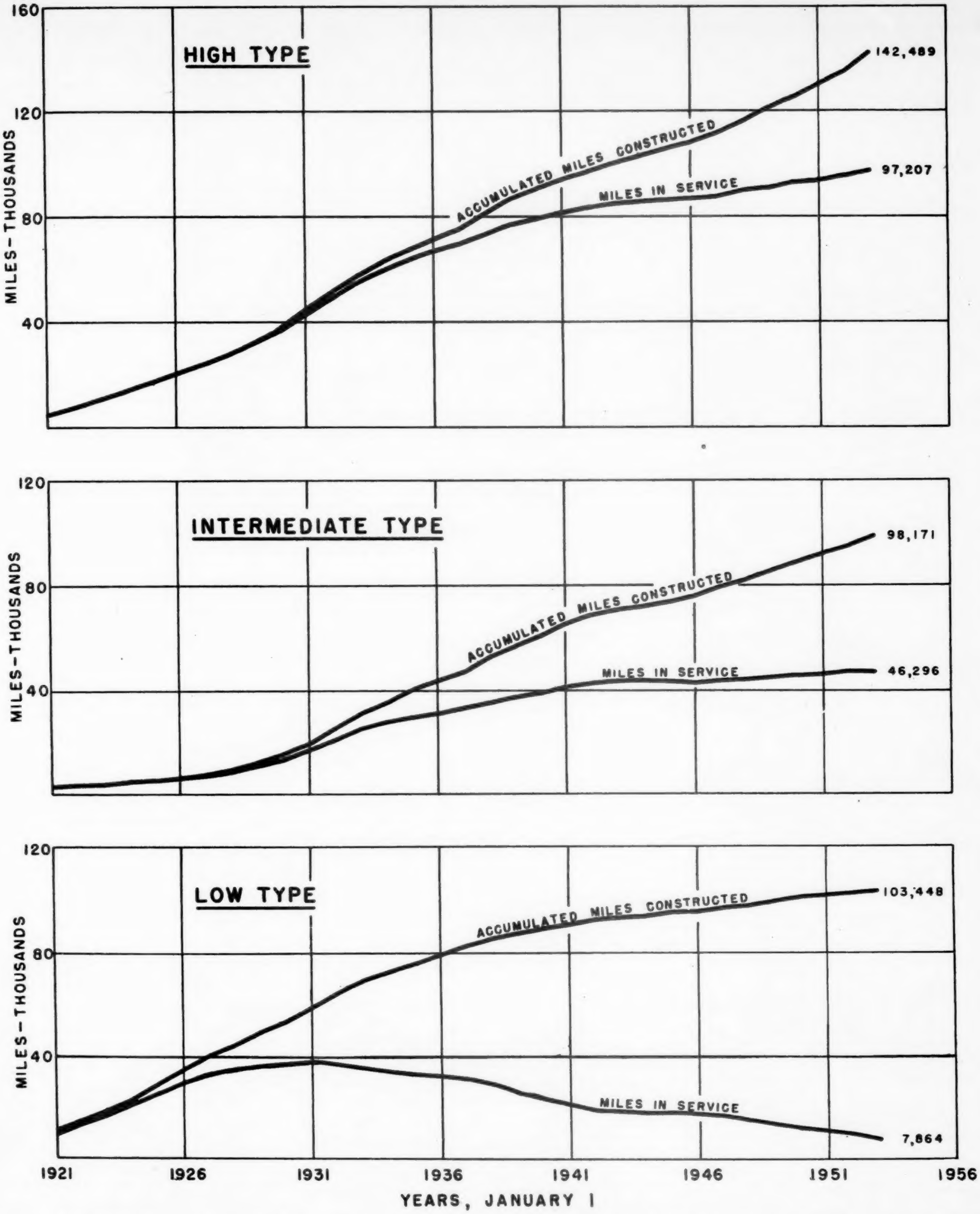

Figure 2.—Accumulated miles constructed and miles in service on rural State or Federal-aid primary systems in 25 States and Puerto Rico, according to low-, intermediate-, and high-type surfaces.

average lives for the most recent years having retirement experience. These assumptions will no doubt vary somewhat from the actual future experience. Since the bulk of the retirements within the next few years will come from the older construction, any minor differences from the assumed average lives for the more recent construction will not have any major effect upon the overall trends which are shown.

Trends in Service Life

Figures 3 and 4 show, for each 5-year construction period, the mileages of low, intermediate, and high types in service up to January 1, 1953, for the 25 States and Puerto Rico, and the probable rates at which these mileages will go out of service. Table 6 shows the total mileages in service on January 1, 1953, and the probable amounts which will still remain in service for 5, 10, 15, and 20 years in the future.

Table 2 shows the probable average lives for various construction-year periods. The

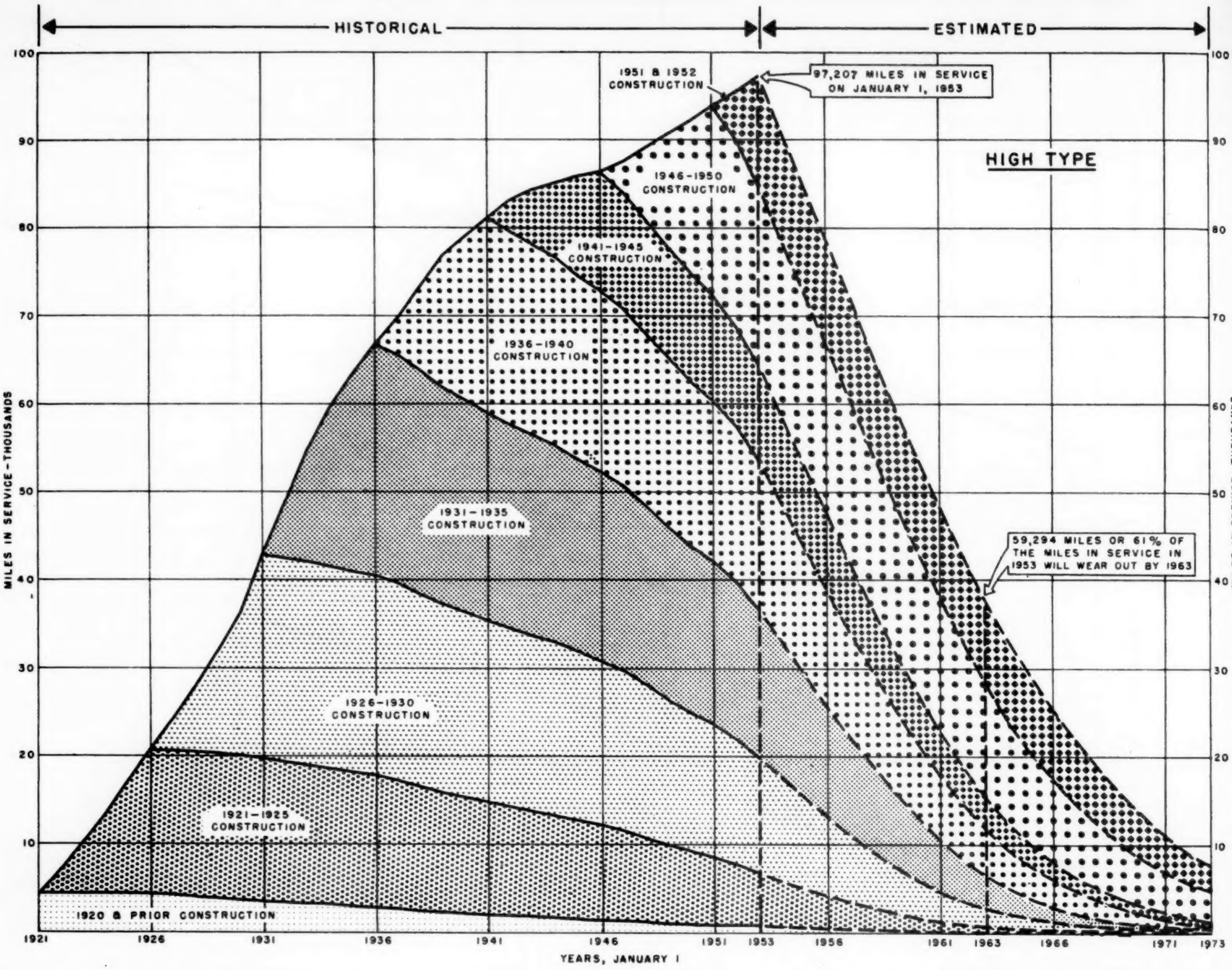

Figure 3.—Of the miles of high-type surfaces on rural State or Federal-aid primary systems in 25 States and Puerto Rico as of 1953, 61 percent will wear out by 1963.

average lives are the expectancies at the time of construction or at age zero. As the road system develops and becomes older, the average age of the surfaces increases and the remaining life expectancy becomes less. Also, as the system becomes older, mileages of earlier retirements are taken out of service; thus leaving in service a preponderance of those mileages with service lives exceeding the average life of the total original construction.

Table 6.—Mileage in service on January 1, 1953, and estimated percentages which will remain in various future years [1]

Surface type	In service on Jan. 1, 1953	Remaining in service on—			
		Jan. 1, 1958	Jan. 1, 1963	Jan. 1, 1968	Jan. 1, 1973
	Miles	*Percent*	*Percent*	*Percent*	*Percent*
Low	7,863.6	16.3	3.6	0.3	[2]
Intermediate	46,295.9	48.6	17.0	4.4	0.9
High	97,207.5	67.5	39.0	19.1	8.0
Total	151,367.0	59.0	30.4	13.7	5.4

[1] Based on analyses of data submitted by 25 States and Puerto Rico for rural State or Federal-aid primary systems.
[2] Less than 0.05 percent.

Life Expectancy

The probable life of the mileage in service is equivalent to the age plus the expectancy. Under certain conditions it is possible for the average age of mileage in service to exceed the average lives shown in table 2. This is true for low-type surfaced mileage, from which the miles in service have gradually been diminishing since 1931 (see fig. 4). Low types, when retired, tend to be replaced by intermediate or high types. Thus, there has not been sufficient construction of new low types to keep the average age of all low types in service from increasing from year to year. As a result, the low types now in service are quite old and have a short expectancy.

Table 7 shows the average age, remaining life expectancy, and total probable life of the mileages of low, intermediate, and high types in service, at 5-year intervals from January 1, 1921, to January 1, 1951; and a 2-year interval from January 1, 1951, to January 1, 1953. This information is also presented graphically in figure 5, which shows the effect of increasing age and decreasing expectancy of mileages in service.

The age of the three major type groups, as shown in table 7, has been increasing from 1921 to 1951. Similarly, the expectancy has been decreasing. Since 1951, there has been a leveling off which suggests that a period of stability has been reached. One means by which a more favorable condition with respect to expectancy can be obtained is by replacing worn-

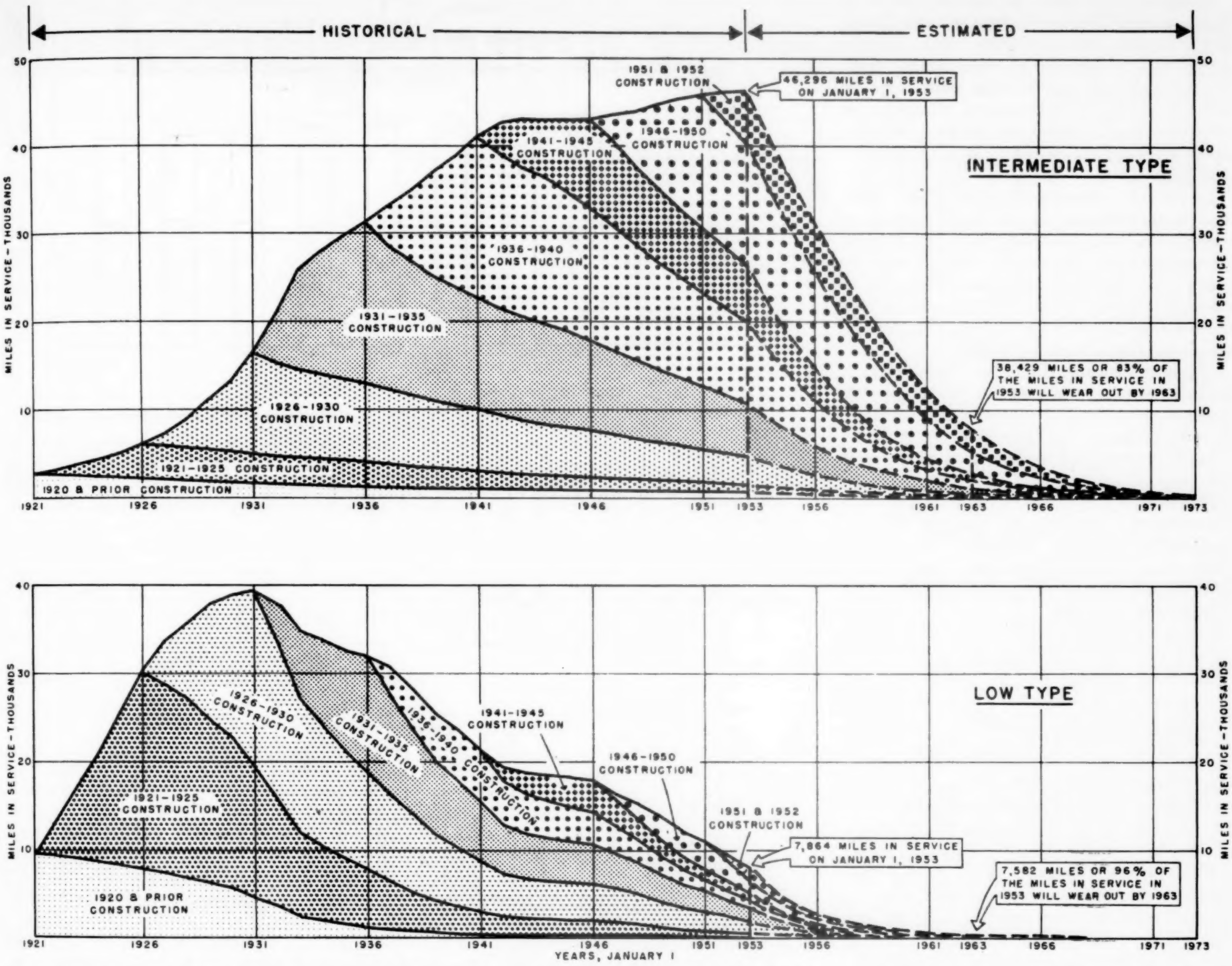

Figure 4.—Of the miles of intermediate- and low-type surfaces on rural State or Federal-aid primary systems in 25 States and Puerto Rico as of 1953, 83 percent of the intermediate type and 96 percent of the low type will wear out by 1963.

out roads with new ones having a longer service life. This, of course, means greater construction expenditures to build the new roads to the higher standards.

Road Life Studies Essential

The data presented relate only to the mileage of road surfaces constructed and retired. Road life studies also embrace research in construction costs, maintenance costs, and salvage values for elements of the highway, including grading and structures. Knowledge on these subjects will be extended as additional States bring their basic studies up to date and as these studies are continued and extended. The objective of efficient and economical management of the highway program is to provide facilities at such locations and to such standards that they can absorb the inevitable and continuing changes in traffic requirements with the least effect upon the ability of the highway plant to provide the maximum service at minimum cost. Data obtained periodically from road life studies are among the essential facts that contribute to the attainment of this objective.

Table 7.—Average age, life expectancy, and probable life of mileages in service at 5-year intervals to 1951 and 1-year intervals thereafter [1]

January 1,	Low-type surfaces			Intermediate-type surfaces			High-type surfaces		
	Age	Expectancy	Probable life	Age	Expectancy	Probable life	Age	Expectancy	Probable life
	Years	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
1921	3.6	9.6	13.2	4.7	16.8	21.5	3.5	18.7	22.2
1926	3.8	7.9	11.7	4.7	16.8	21.5	3.5	21.3	24.8
1931	5.3	6.7	12.0	4.2	14.5	18.7	4.9	19.9	24.8
1936	6.6	7.2	13.8	5.5	12.3	17.8	7.0	17.0	24.0
1941	8.7	7.3	16.0	7.0	11.2	18.2	9.3	14.7	24.0
1946	11.7	5.0	16.7	9.7	8.5	18.2	12.3	11.4	23.7
1951	12.9	3.3	16.2	10.6	6.6	17.2	13.4	9.5	22.9
1952	13.1	2.9	16.0	10.8	6.1	16.9	13.6	9.2	22.8
1953	13.0	2.9	15.9	10.9	5.9	16.8	13.3	9.3	22.6

[1] Based on analyses of data submitted by 25 States and Puerto Rico for rural State or Federal-aid primary systems.

APPENDIX

Surface Type Definitions

Soil-surfaced road.—A road of natural soil, the surface of which has been improved to provide more adequate traffic service by the addition of (1) a course of mixed soil having A–1 or A–2 characteristics, such as sand-clay, soft shale or topsoil, or (2) an admixture such as bituminous material, portland cement, calcium chloride, sodium chloride, or fine granular material (sand or similar material).

Gravel or stone road.—A road the surface of which consists of gravel, broken stone, slag, chert, caliche, iron ore, shale, chat, disintegrated rock or granite, or other similar fragmental material (coarser than sand) with or without sand-clay, bituminous, chemical, or portland cement stabilizing admixture or light penetrations of oil or chemical to serve as a dust palliative.

Bituminous surface treated road.—An earth road, a soil-surfaced road, or a gravel or stone road to which has been added by any process a bituminous surface course, with or without a seal coat, the total compacted thickness of which is less than 1 inch. Seal coats include those known as chip seals, drag seals, plant-mix seals, and rock-asphalt seals.

Mixed bituminous road.—A road the surface course of which is 1 inch or more in compacted thickness composed of gravel, stone, sand, or similar material, mixed with bituminous material under partial control as to grading and proportions.

Bituminous penetration road.—A road the surface course of which is 1 inch or more in compacted thickness composed of gravel, stone, sand, or similar material bound with bituminous material introduced by downward or upward penetration.

Bituminous concrete, sheet asphalt, or rock asphalt road.—A road on which has been constructed a surface course 1 inch or more in compacted thickness consisting of bituminous concrete or sheet asphalt, prepared in accordance with precise specifications controlling gradation, proportions, and consistency of composition, or of rock asphalt. The surface course may consist of combinations of two or more layers, such as a bottom and a top course or a binder and a wearing course.

Portland cement concrete road.—A road consisting of portland cement concrete with or without a bituminous wearing surface less than 1 inch in compacted thickness.

Brick[5] *or block road.*—A road consisting of paving brick, stone block, wood block, asphalt block, or other form of block, with or without a bituminous wearing surface less than 1 inch in compacted thickness.

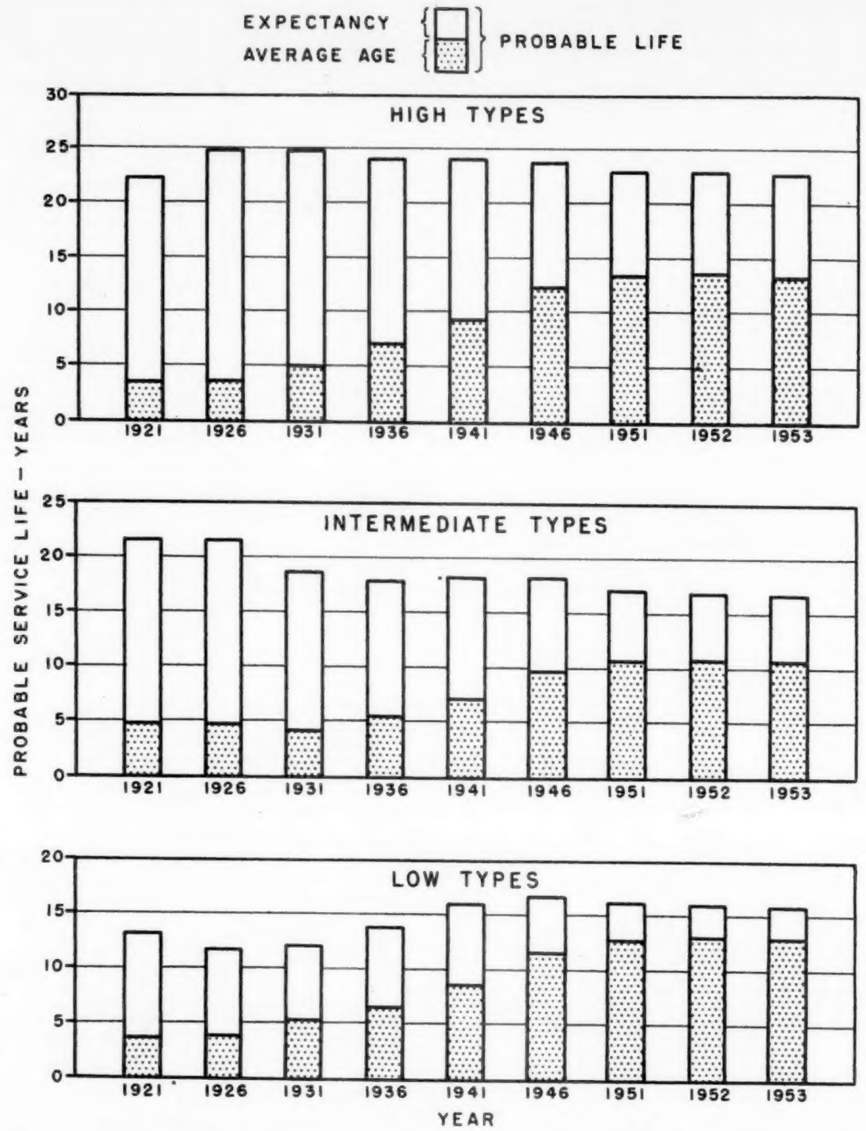

Figure 5.—Trends in average age, expectancy, and probable life of surfaced mileage on rural State or Federal-aid primary systems in 25 States and Puerto Rico for 5-year intervals 1921–51, and for 1952 and 1953.

Methods of Retirement

Resurfacing.—Roads which are resurfaced or used as a base for the replacement type are so classified when the old surface is utilized more or less intact (with the exception of necessary scarifying, reshaping, or partial reworking of the surface) in the new construction which retires the old surface. Examples of this method are the retirement of a soil-surfaced road by surface treating, or the retirement of a gravel or stone road by utilizing it as a base or foundation for a mixed bituminous road or a bituminous penetration road. For surfaces which are retired by this method, it is obvious that the new or replacement construction must necessarily be along the same alinement and practically the same grade.

Reconstruction.—When surfaces are retired by reconstruction, there is little or no salvage of the old surface and base. This classification includes old surfaces and bases that are torn up and not reused. Usually for types that are retired by this method, the replacement type is built along the same general alinement (generally within the limits of the existing right-of-way) with only minor improvements in horizontal curvature. Substantial improvements are usually made with respect to grades, however.

Abandonment.—When the new construction is on new location, the old road is classified as abandoned when it is no longer maintained or kept in service at public expense. The abandoned road may revert to a private road, be barricaded to public travel, or be removed. Sometimes because of changes in land usage, such as abandonment of factories, and removal or construction of railroad facilities, roads may be abandoned without involving new construction.

Transfer.—A retirement by transfer is similar to an abandonment except that the old road is continued in service after being dropped from the State or Federal-aid system and is maintained by county or other authority responsible for the upkeep of roads not on the State or Federal-aid system. A transfer is not a retirement in the sense that the road has rendered its total service to the public, but merely that it has rendered its complete service as a primary State or Federal-aid highway. Retirements by transfer are generally the result of functional obsolescence involving alinements and grades which are unsatisfactory for existing traffic conditions. A new road is built on new alinement and improved grades, and the old road remains in service usually because of the necessity of providing for local traffic usage. After the new road is placed in service on the State or Federal-aid highway system, the State will no longer wish to maintain the old road, and the county or other local authority generally takes over this responsibility. If the road is no longer used, it is considered an abandonment.

[5] Vitrified paving-brick roads were reported by the States separately from other types of brick or block roads. Because of the small mileages involved, these two types are combined in this article. Approximately 99 percent of the construction of these two types included in the study is vitrified paving brick.

The Investment Analysis Approach to Estimating Highway Needs

BY THE FINANCIAL AND ADMINISTRATIVE RESEARCH BRANCH
BUREAU OF PUBLIC ROADS

Reported [1] by FRED B. FARRELL
Chief, Highway Cost Section

Research on the growth and depreciation of the investment in highways is relatively new. The basic data for such research are obtained from the road-life study phase of the Statewide highway planning surveys. Some of the initial applications of the findings are very promising. One of these, as discussed in this article, involves the estimating of highway needs.

The end product of a highway needs study is, of course, the formulation of a financial plan to meet such needs. This inevitably requires consideration of many financing alternatives, and in the case of credit financing proposals, requires a year-by-year listing of capital outlays required to reach adequacy within a given time period and thereafter to sustain adequacy. Not only does the investment analysis approach provide a quick means of estimating total needs, but it also provides a method of scheduling such needs on an annual basis over extended future periods.

THE time and effort spent by highway departments on highway needs studies over the past few years have paid dividends. The magnitude of the highway problem, locally and nationally, has been brought into proper perspective. The engineer's knowledge of geometric and structural needs has been translated into understandable dollars and cents terms that have become accepted by the general public.

Engineering Approach to Needs

The "engineering approach" is the usual means employed in estimating costs to improve road systems to a state of adequacy. In this approach, data on traffic, condition, deficiencies, and service characteristics are compiled for each individual road section. Engineering field checks and inspections are then made, needs determined, and costs of improvement estimated and identified either as an immediate need or as a future need within the next 5, 10, 15, or 20 years.

Under such an approach most of the needed improvements on existing roads fall in the category of "needed now." Successively lesser amounts show up as being needed each year thereafter. Since any actual improvement program to meet such a needs schedule would not be practical, it is the usual practice to take the results of the engineering approach and rework them in the office so as to produce a realistic program, say for 10 years. This 10-year "catch-up" program would then include all the measured needs within the first 10 years *plus* an allowance for stop gaps and replacements.

Stop gaps represent construction necessary to keep roads in operation until the final improvement can be made. Replacements represent work (principally resurfacing) necessary in the last part of the 10-year period on roads built in the first part of the 10-year period. Some allowance must also be made for those improvements which are "needed now" but which are deferred to the fifth or sixth year of the 10-year catch-up program. When eventually built, the volume of traffic for which they will be designed will be somewhat higher. This could result in an increase in the original cost estimate.

The 10-year catch-up program represents only one condition. For purposes of financial planning, costs of 12-year, 15-year, 20-year, and other catch-up programs must also be prepared and studied. Additionally, it is desirable to develop future costs for the years following the catch-up period so as to enable long-range credit financing proposals to be worked out. In these particular cases, money is borrowed during the catch-up period and repaid afterwards. Obviously, a sound financing plan must take into account not only the debt repayment but also the construction and replacement needs in the years following the catch-up period.

In summary, the outstanding advantage of the engineering approach, especially for the principal road systems, is that it produces a clear cut, supportable cost estimate based upon study of the physical needs of individual road sections. Substantial amounts of time and effort are required, however, in making these estimates in the first instance. And although progress is being made in streamlining the engineering approach, there is at present no quick and easy means of rearranging, recasting, and spreading out basic needs study data so as to provide long-range, year-by-year, cost estimates for the many program alternatives that crop up in planning a financial program.

Investment Analysis Approach to Needs

The "investment analysis approach" offers considerable promise in this respect. This approach can be used in those States and on those road systems where the road life study is up to date. It is based upon the premise that under a condition of sustained traffic increase over a period of several years, there should be a corresponding increase in the investment (cost-new less depreciation) in the highway plant.

In other words, if traffic were to increase 40 percent over the next 10 years there would need to be a corresponding increase of about 40 percent in the investment in highways over these same 10 years. Of course, today's highways are not adequate. Hence, unless this backlog of existing deficiencies is also overcome, the 40-percent increase in investment over a 10-year period would not result in adequate highways. It would simply continue to keep the highways at the same relative position with respect to meeting traffic needs at the end of 10 years as they are today.

An illustration may clarify this point. Three years ago, the results of a nationwide study of capital investment in highways were reported at the annual meeting of the Highway Research Board.[2] Figure 1 is taken from this study. It shows three curves, all based on January 1, 1953, price levels. The top curve shows the accumulated capital outlays made for all roads and streets in the United States up to January 1, 1953. The middle curve shows the amounts remaining in service after making deductions for construction work that had been retired and is no longer in existence. It represents the original cost (new) of all roads and streets still remaining in service. But all of these roads and streets are not brand-new. They have aged and a portion of their original service life has been used up. In other words, they have depreciated. The depreciated amounts are represented by the bottom curve.

It may be well at this point to note that the basis for computing this chart was the yearly outlays for construction. The accumulation

[1] This article was presented at the 35th Annual Meeting of the Highway Research Board, Wash., D. C., Jan. 1956.

[2] *The capital investment in highways*, by Fred B. Farrell and Henry R. Paterick. Proceedings of the Highway Research Board, vol. 32, 1953, pp. 1–11.

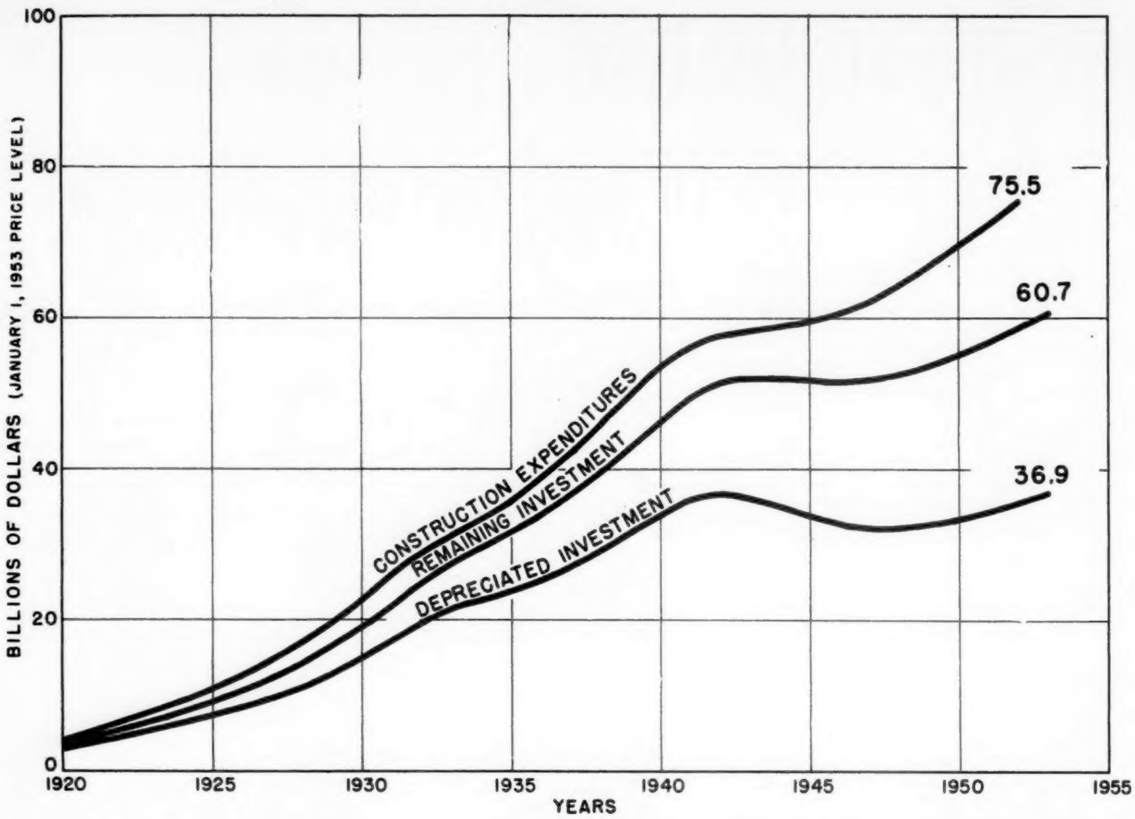

Figure 1.—Accumulated construction expenditures, remaining investment, and depreciated investment for all roads and streets in the United States up to January 1, 1953.

of these construction amounts is the top curve. From this top curve as a starting point the road-life study data and analysis procedures make it possible to compute the bottom curve—depreciated investment. Conversely, if the starting point had been the bottom curve—if all that was known was the trend in depreciated investment—it would be possible to reverse the computations to find out what the construction amounts are. This is called the "reverse computation," and the process is mentioned later.

In summary, figure 1 shows that up to January 1, 1953, (1) $75.5 billion had been spent for construction of all roads and streets in the United States, (2) $60.7 billion was the amount (cost-new) still in service, and (3) this total, when depreciated for service already consumed, amounted to $36.9 billion. It is the bottom curve, depreciated investment, that is primarily involved in the investment analysis approach. It is this trend that should correspond to the traffic trend.

The solid curve in figure 2 shows the trend in depreciated investment referenced to the years 1937–41 as a base of 100. This trend corresponds to the one for depreciated investment (bottom curve of fig. 1), with the exception that it includes certain minor adjustments due to price index revisions that were later considered desirable.

Selection of Base Period

The years 1937 to 1941 have been selected as a base of reference because they represent one of the most favorable periods in the development of highways. True, there were many highway needs during this period. But on the average it was a period during which highways reached their highest level of development in relation to the traffic demands imposed upon them. Prior to this period there was a sustained increase in the level of development. Subsequent to this period and after World War II, the traffic growth far outstripped growth of the highway plant.

Gap Between Investment and Traffic Widens

This can be readily seen by inspection of the traffic trend which is plotted as a dashed curve in figure 2. There is a similarity in the two trends up to 1941. The traffic then fell off until 1944, made a rapid recovery, and since 1946 has been increasing steadily. The trend in depreciated investment likewise dipped during the war. This was due to the fact that highways continued to depreciate during a period when capital outlay was drastically curtailed. After the war a slow recovery began—much slower than the traffic trend. Inspection of figure 2 shows just how slow it was. In fact it took 7 years of postwar construction for the depreciated investment to overcome the wartime dip and recover to the level of 1941.

The similarity of the two trends in the prewar years is sufficient to raise a question as to whether such similarity might not have continued in the postwar years under an adequate highway program. Certain rough computations made during 1953 seemed to support this hypothesis. Assuming that the hypothesis was correct, it would follow that if traffic could be predicted for the future, then the level of needed highway investment could likewise be predicted. Then, by knowing the existing level of investment and the future level of needed investment, it would be a simple matter to compute the annual capital outlays necessary to raise the depreciated investment from one level to the next. This would be done by the "reverse computation" process previously mentioned. It would give the construction needs.

Application of Reverse Computation Process

An opportunity presented itself to test this theory early in 1954. At that time a highway needs study using the engineering approach was being made in West Virginia, the results of which would not be available until mid-year. In the meantime, studies had been made in West Virginia of probable future travel trends. Also available were the results of the salvage value and investment analysis which were made as part of the road life study on the primary rural State highway system of West Virginia and which covered all construction and retirements up to 1954.

With this as a starting point, an analysis of the investment in the system was made which produced a series of values for the depreciated investment in terms of constant 1953 dollars for each year up to January 1, 1954. The resulting trend was then referenced to a base period (1937–41 = 100) and compared with the travel trend and its future extension. These two trend lines are shown in figure 3. There is a wide gap between the two trends in 1954.

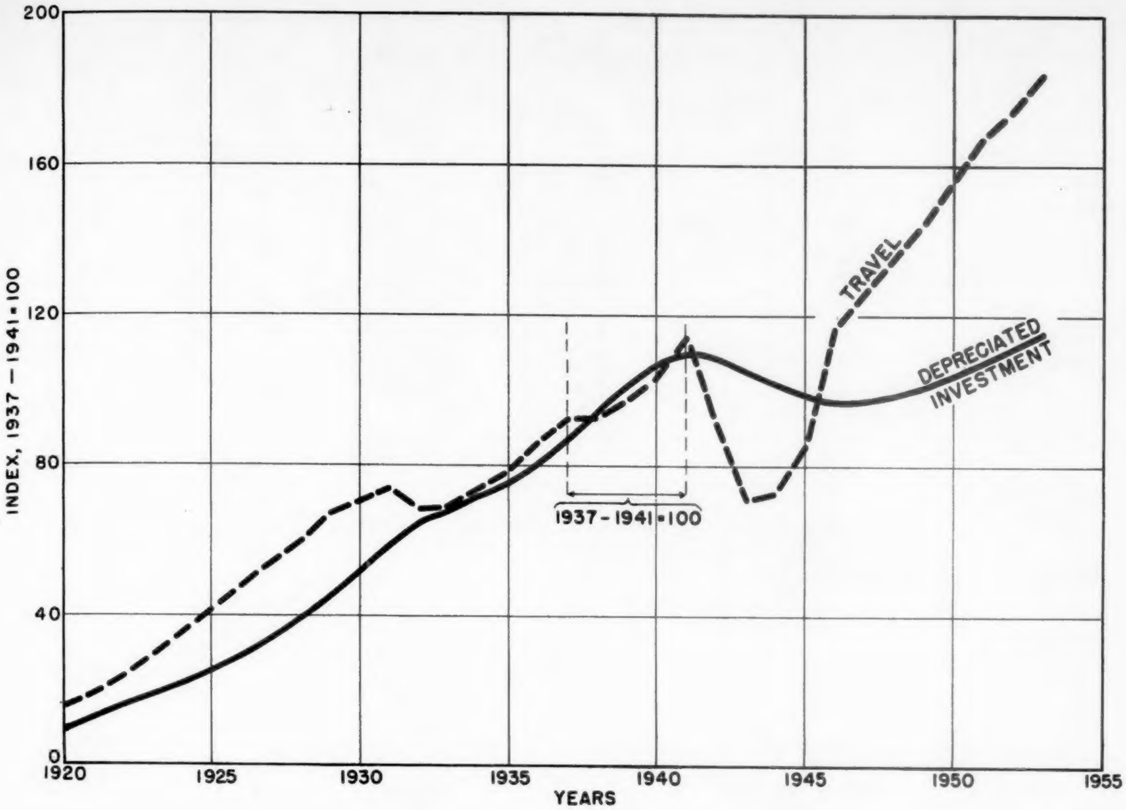

Figure 2.—Trends in travel and depreciated investment for all roads and streets in the United States up to January 1, 1953.

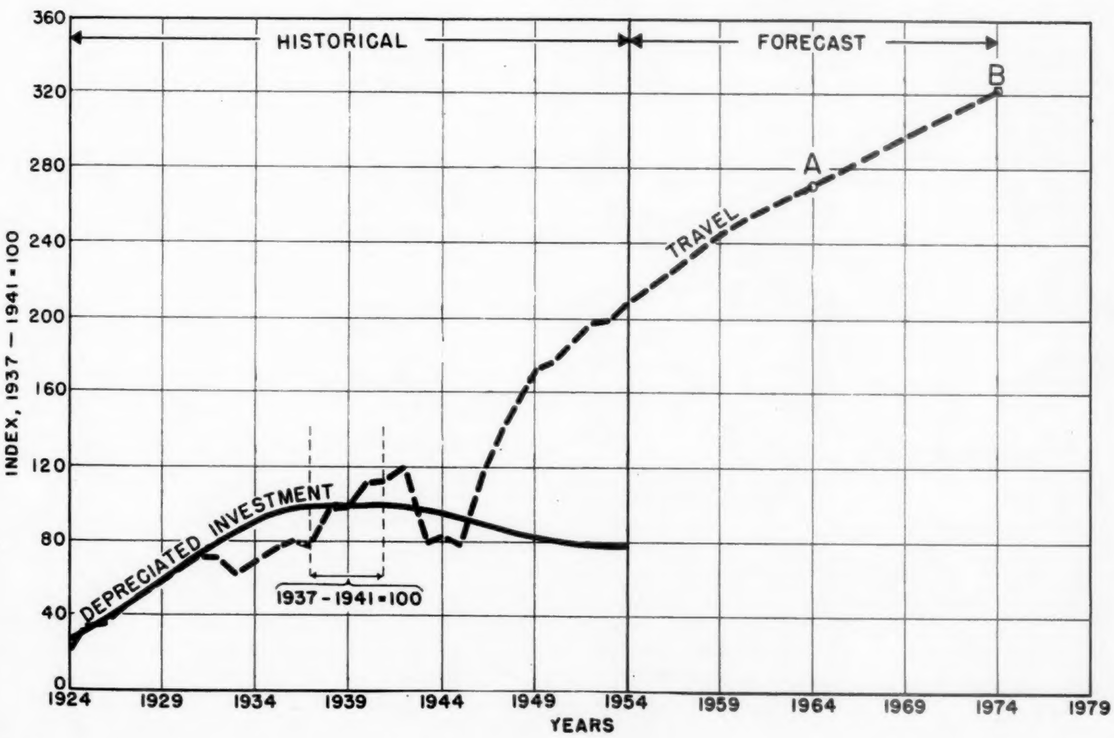

Figure 3.—Trends in travel and depreciated investment for the primary rural State highway system in West Virginia.

The next step was to test the theory that the trend in needed investment should basically be the same as the travel trend. To do this simply involved the assumption that for a 10-year program, for example, the trend in depreciated investment would catch up to the travel trend in 10 years (to point A by 1964). If a 20-year program was assumed, it would catch up in 20 years (to point B by 1974); and so on for any selected catch-up period. Once the trend in depreciated investment catches up to the travel trend, it is assumed that adequacy will be sustained thereafter. This means the investment trend then becomes identical to the travel trend.

Next, computations were made of the construction amounts necessary to raise the level of investment up to the travel trend to points A, B, and other selected catch-up program periods. This was done by the "reverse computation" process. To do this required certain assumptions as to the investment lives of recent and future construction of various roadway elements: grading; low-, intermediate-, and high-type surfacing; and structures. The decision as to the proper service lives to use in these cases is the most critical part of the analysis. However, it is probably no more critical than certain decisions that must be made when evaluating needs on a project-by-project basis in the engineering approach. Such estimates of service lives, of course, can be reasonably approximated from a study of past trends.

Allowances must also be made for the increases in service lives that will result when

roads are rebuilt to the structural and geometric design standards called for in the needs studies. It is quite possible, for example, that the service life of future surfacing would be increased by as much as 25 percent over the present average. For grading on the highest type roads, future service lives may be as much as 75 to 100 percent greater.

Needs Computed for Three States

The cost estimates developed from the engineering approach in West Virginia became available in mid-1954. These estimates were then compared with the earlier ones of the construction needs computed in reverse by the investment analysis approach previously described. The agreement between the two estimates seemed to bear out the reasonableness of the latter approach. The following is quoted from pages 59–61 of the 1954 report "A Factual Study of Highway Needs in West Virginia [3]":

> A completely separate statistical analysis of capital investment, excluding right-of-way, in the rural State primary system was prepared as part of this study . . .
>
> Adjusted to 1953 price levels and reduced 10 percent to represent the proposed rural State Trunkline System, the analysis shows that:
>
> $38 million annually would be required for construction alone to meet traffic needs in 20 years. That compares with $35 million per year derived from the field studies . . .
>
> A 15-year program, for construction only, would require $47 million annually, compared to $45 million determined by field studies. . . .
>
> * * * * *
>
> . . . The field study results are less than, but similar to, the investment analysis, although developed on a wholly different basis. The similarity gives assurance that both methods are adequate . . .

Subsequently, similar analyses were made for the rural primary highway systems of Missouri and Washington. In each case reasonable approximations of total needs were obtained. Additional studies are now being made for other States where road life studies are sufficiently far advanced.

Research on the investment analysis approach is still in its initial stages. There is, however, one general finding that warrants mention. It has been found that over a 30-year period, the total capital outlay needed to build an adequate highway system and thereafter keep it adequate is about the same regardless of the time taken for the initial catch-up program.

This is shown in figure 4 for 10-, 20-, and 30-year catch-up programs. Data used are averages for the rural primary systems of Missouri, Washington, and West Virginia. The height of the bars represents the total construction costs over a 30-year period. The total costs are about the same in all three cases, the principal differences being in the relative amounts needed in the first and second decades of each catch-up program. In other words, the first bar shows that for a 10-year catch-up program, there would be a heavy expenditure in the first decade while catching up to adequacy. Thereafter, in the second and third decades the cost to sustain adequacy would be somewhat less. For the 30-year catch-up program, on the other hand, the costs would be the least in the first 10 years and successively greater in the next 2 decades. Total costs over 30 years would be about the same in each instance. But in one case, the road system would become adequate in 10 years and thereafter be kept adequate. In the other case, the road system would not become adequate until 30 years have passed.

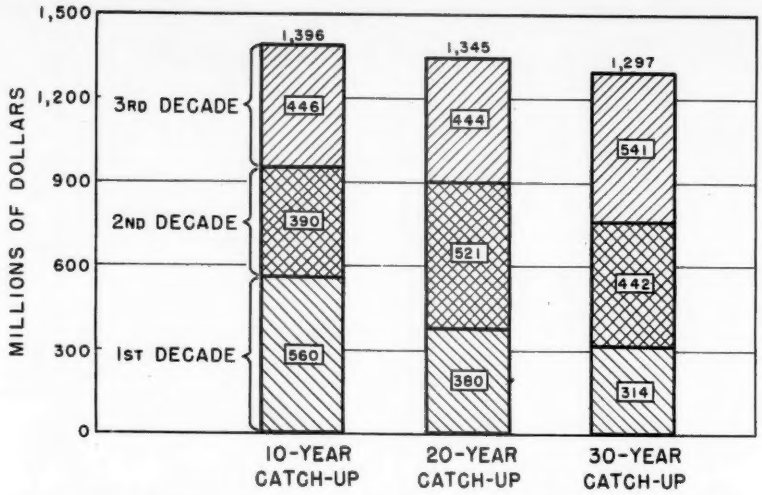

Figure 4.—Average construction needs in terms of 10-, 20-, and 30-year catch-up programs for the rural State primary systems in Missouri, Washington, and West Virginia.

Evaluation of Investment Analysis Approach

Perhaps the most attractive feature of the investment analysis approach to estimating highway needs is the ability to process the data in various ways. For example, in the study of alternative financing plans, it is desirable to have a year-by-year array of construction needs during various catch-up periods, say 10, 12, 15, and 20 years. It is also desirable to have a year-by-year array of future needs for 10, 20, or even 30 years after the shorter catch-up periods. Similarly, it may be desirable to know at what rate the highway needs will be overcome under various financing proposals.

The investment analysis approach can provide such data readily. Its outstanding advantages are the speed with which needs estimates can be prepared, the small amount of manpower required, and its extreme flexibility in arraying needs data in various ways. But there are also disadvantages in that it treats road systems as lump sums rather than by individual road sections.

Possibly the best circumstances exist in those cases where a State has *both* the results of an engineering study of needs and an up-to-date road life study. In such instances, the investment study can be used as a means of introducing flexibility into the engineering study results. As a case in point, a given State may have a well developed engineering study which provides an estimate of the cost of bringing each road section up to adequacy within 10 years. With such information as a base, the investment analysis approach can then be used to adjust the needs study findings to show costs of 12-, 15-, and 20-year, or any other catch-up period and to extend them into the future beyond the catch-up period.

Further, there are cases where a needs estimate has been prepared upon certain assumptions as to future traffic growth. If these assumptions were to be changed for one reason or another, it would obviously affect the needs estimate. The making of such revisions could pose considerable difficulties in the engineering approach. Under the investment analysis approach a revised estimate could be prepared quickly.

Additional investment studies and further refinement of the analysis processes are desirable before specific relations and findings can be presented which will adequately reflect the widely varying conditions encountered in the various States. The concept and technique of analysis are, however, quite simple. Preliminary results attest to the reasonableness of the investment analysis approach. They give indication that this product of the road life study can be effectively used in estimating highway needs for various conditions of future traffic and in arraying such needs on a year-by-year basis for financial planning purposes. The advantages of the investment analysis approach become doubly apparent in States where the road life study is up to date. In such cases, the staff and time requirements for the analysis are only a fraction of those needed for the engineering approach.

[3] A report to the West Virginia Legislative Committee. Prepared under the terms of House Concurrent Resolution No. 4, adopted Feb. 5, 1953.

A Six-State Classification Study of Engineering Personnel

BY THE FINANCIAL AND ADMINISTRATIVE RESEARCH BRANCH BUREAU OF PUBLIC ROADS

Reported [1] by RALPH S. LEWIS, Chief, Financial and Administrative Studies Section

Because an earlier study revealed wide variations in the number of engineers employed by the several State highway departments per million dollars of capital outlay for highways, analyses were made in six States to determine the significance of these variations. The earlier study, made in 1954, indicated a range of 2.0 to 28.2 engineers per million dollars of capital outlay among all States.

It was realized, of course, that differences among the States in classifying and reporting engineering personnel might account to a considerable extent for the variations, but the possibility that the variations might be indicative of relative operating efficiency was also considered. In an effort to explain the variations, studies of engineering classification and related matters were conducted during the summer and fall of 1955 in Mississippi, Nebraska, Oregon, Vermont, Washington, and Wisconsin.

It was found that classification procedures and reporting methods definitely affect the results reported by the earlier study. Two of the six States studied, for example, had reported only registered engineers, while the other four States had reported all personnel classified as engineers by civil service or merit system provisions, regardless of professional qualifications.

The present six-State study reveals that of the 2,114 employees classified as engineers, only 31 percent were registered engineers, 35 percent were civil engineering graduates (about half were registered), and 52 percent were neither civil engineering graduates nor registered.

This article also relates the number of engineers employed to the number of subprofessional employees, to program characteristics, and to management practices and procedures. The findings are not conclusive, because of the many intangibles involved and the relatively few States included in the study. It is established, however, that by combining the number of engineers and engineering aids the extreme variations in the number of engineering employees per million dollars of capital outlay are reduced considerably.

[1] This article was presented at the 35th Annual Meeting of the Highway Research Board, Wash., D. C., Jan. 1956.

A STUDY was undertaken by the Highway Research Board late in 1954 to determine the number of professional engineers employed by all State highway departments, the number of engineering positions it would be necessary to create in order to handle the work then being handled by consulting firms, and the number of additional engineers needed in order to work at the highest level of effectiveness.[2] The States reported a total of 18,034 engineers employed, consulting work equivalent to another 4,192 engineering positions, and a need for 3,990 additional engineers for fully effective work.

Subsequent analysis indicated that the number of engineers reported per million dollars of capital outlay varied from 2.0 to 28.2 in the individual States. These wide variations were somewhat of a surprise, and their possible significance prompted further study. It was realized, however, that differences among the States in classifying and reporting engineering personnel might account to a considerable extent for the variations.

There was also the possibility that the variations might be indicative of relative operating efficiency. If so, it seemed likely that those States with a low number of engineers per million dollars of capital outlay might furnish ideas for the utilization of engineering manpower which would be of value to other States. In any event, no conclusions could be reached without a much more detailed analysis.

Accordingly, it was decided to make a detailed study of engineering classification and related matters in six selected States—Mississippi, Nebraska, Oregon, Vermont, Washington, and Wisconsin. In selecting these States, consideration was given to the relative number of engineers per million dollars of work, geographic location, rural-urban characteristics, total amount of program, amount of work done by consultants, and number of additional engineers needed for fully effective work. Information on the number of engineers employed per million dollars of capital outlay for the six States selected is presented in table 1, on the basis of data reported in the 1954 study.

That study, in asking for information on the number of professional engineers employed, defined a professional engineer as a "registered professional engineer, or one qualified to register." Since this definition was subject to interpretation by the States, it was decided that one of the primary concerns of the new studies should be the professional qualifications of employees classified by the States as engineers. Also, it was decided to extend the studies to include engineering aids, as well as engineers, and to relate the number of engineers and engineering aids employed to both program characteristics and management practices and procedures. Such studies were conducted in each of the selected States during the summer and early fall of 1955.

[2] *Engineering-personnel needs for highway departments*, by M. Earl Campbell and L. R. Schureman. Highway Research Board, Bulletin 106, 1955.

Classification Plans of the Several States

Since these studies are concerned primarily with classification, it is desirable at this point to comment briefly on the classification plans of the States included in the studies. The highway departments of Oregon, Vermont, Washington, and Wisconsin all operate under formal civil service systems and have classification plans of the graded type; that is, Engineer I, II III, IV, V, and Engineering Aid I, II, III, or A, B, C, and so forth. The Nebraska Department of Roads and Irrigation has for years maintained an informal merit system for its technical employees, and also has a graded classification plan. In Mississippi, job titles are related to specific duties, such as junior engineer of final plans, senior instrumentman, junior draftsman, rodman, and others which are difficult to correlate with the several classes of a graded classification plan.

Moreover, even in the five States with graded classification plans, correlation is not a simple matter. There are several reasons for this. In the first place, a graded classification plan usually includes in addition to engineers and engineering aids, several miscellaneous classes such as draftsman, radio technician, laboratory technician, traffic recorder, and on occasion even laborer, which can be included in either the engineer or engineering-aid categories, and sometimes in both. Also, the duties performed by an Engineer I in some States are performed by high-grade engineering aids in other States. In most States a civil engineering graduate can be hired as an

Engineer I, but in others he must be hired as an engineering aid and cannot be classified as an engineer until certain service requirements have been met.

The matter of registration is a confusing one, too. Some States require that engineers in a particular classification or salary scale be registered, but others require registration only in connection with certain duties. Also, some States require registration for particular grades, while others require only eligibility for registration. In Wisconsin, for example, an Engineer IV must be eligible for registration, while an Engineer V or higher must be registered. In Oregon, classification as a Civil Engineer IV or higher requires registration. Registration at the associate engineer level is preferred in Washington and is required at the senior and higher levels. In Mississippi, only field engineers at the project level and higher are required to be registered.

All of this discussion indicates, of course, that there are wide differences in the qualifications of the engineers classified as such by the several States. It also suggests that there may be some variation among the States in the relation of classification to duties. Both are important matters in determining the number of engineers employed by the State highway departments, but because of time limitations it was impossible to conduct the interviews necessary to determine the relation of classification to duties. The number of civil engineering graduates and registered professional engineers included among the classified engineers in each State was tabulated, however.

Although the 1954 study reported engineers employed, those equivalent to consulting work, and additional engineers desired, the six-State study is concerned only with engineers employed, because of the intangibles involved in studying the other two categories. Also, while the 1954 study reported engineers by function to which assigned, such as construction, design, maintenance, and so forth, this functional distribution is not carried forward here because of the relatively few engineers assigned to other than a few major functions. In computing the number of engineers employed per million dollars of capital outlay, however, those assigned to maintenance are omitted in all cases, because their efforts do not affect the capital outlay accomplishment.

It should also be pointed out that in most cases the number of engineers employed in a particular State does not change much from year to year, nor from season to season.

Table 1.—Engineers employed and number per $1 million of capital outlay in six selected States

State	Number of engineers [1] assigned to—			Capital outlay [2]	Engineers employed per $1 million of capital outlay [3]
	Maintenance	Other than maintenance	Total		
				Million dollars	
Mississippi	11	100	111	26.3	3.8
Nebraska	20	225	245	16.5	13.6
Oregon	26	426	452	40.1	10.6
Vermont	25	128	153	5.2	24.6
Washington	12	194	206	46.3	4.2
Wisconsin	34	388	422	33.4	11.6
Total	128	1,461	1,589	167.8	8.7

[1] As reported in Highway Research Board Bulletin 106, 1955, p. 4.
[2] *Highway statistics*, 1954, Bureau of Public Roads, table SF-4, p. 55.
[3] Excluding those assigned to maintenance.

Neither does the number of engineering aids change much from year to year, although this number may change substantially at different seasons of the year. Program amounts in a particular State, however, may vary widely from year to year with a corresponding pronounced effect on the number of engineering employees per million dollars of capital outlay.

Conclusions

Generally, the findings of the six-State study are relative rather than absolute or final. The fact that only six States are included is itself a limiting factor. For any particular State, the information reported here might have been widely different a year ago, or might change radically during the course of the next year. Whether the six States selected for study are representative of the other States is not known. Nevertheless, it is believed that the studies contribute materially to the overall engineering manpower problem, if only because of the questions they raise.

With respect to the wide variations in the number of engineering employees per million dollars of capital outlay in the individual States, as reported in the 1954 study, some of the variations have been explained satisfactorily, and some have not. In any event the complexity of the situation has been demonstrated. It appears that the variations are influenced by a number of factors, and that some of them lend themselves to analysis, while others do not. Whether or not the ratio of engineering employees to capital outlays is a valid indication of overall operating efficiency remains a moot question.

The really significant finding, however, is that no one really knows how many engineers or how many engineering aids are employed by the several State highway departments. Much has been written about the current shortage of engineers, and of the States' needs and requirements in connection therewith, but certainly an accurate tabulation of present engineering employees is prerequisite to a solution of the problem. Under the circumstances, a new and more definitive overall study is desirable, so that data for all States can be reported on a uniform basis.[3]

Qualifications of Engineers

Table 2 shows the number and qualifications of highway department employees classified as engineers in each of the six States selected for further study. The classification concept used here is of course different from the "professional engineer" concept of the 1954 study, and is quite revealing. It is first noted that the difference between the 2,114 engineers of table 2 and the 1,589 total of table 1 is accounted for largely by two States—Mississippi and Washington. After some discussion with the appropriate State personnel, it was discovered that for the 1954 study Mississippi had reported only registered engineers, while Washington had reported only engineers of the associate or higher grades, omitting the junior and assistant grades. Each of the other States had reported all engineers classified as such, regardless of their professional qualifications or grades.

Thus, the reported total of 18,034 engineers employed by all State highway departments may be either high or low, depending on what

[3] The Highway Research Board is undertaking a census of the State highway department engineering employees as of March 1, 1956. Results should be available by July 1.

Table 2.—Number and qualifications of State highway department employees classified as engineers in six selected States

State	Civil engineer graduates and registered		Civil engineer graduates only		Registered engineers only		Neither graduates nor registered engineers		Employees classified as engineers		Civil engineer graduates		Registered engineers	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Mississippi	82	38	4	2	34	16	96	44	216	100	86	40	116	54
Nebraska	28	12	25	11	71	30	111	47	235	100	53	23	99	42
Oregon	63	13	77	16	39	8	302	63	481	100	140	29	102	21
Vermont	32	21	33	22	20	13	67	44	152	100	65	43	52	34
Washington	63	10	124	20	56	9	384	61	627	100	187	30	119	19
Wisconsin	115	29	98	24	55	13	135	34	403	100	213	53	170	42
Total	383	18	361	17	275	13	1,095	52	2,114	100	744	35	658	31

Table 3.—Number of employees classified as engineers[1] per $1 million of capital outlay, according to qualifications, in six selected States

State	Civil engineer graduates and registered	Civil engineer graduates only	Registered engineers only	Neither graduates nor registered engineers	Employees classified as engineers	Civil engineer graduates	Registered engineers
Mississippi	3.0	0.2	1.3	3.6	8.1	3.2	4.3
Nebraska	1.5	1.4	3.8	6.2	12.9	2.9	5.3
Oregon	1.3	1.9	.8	7.1	11.1	3.2	2.1
Vermont	6.0	6.3	3.8	12.9	29.0	12.3	9.8
Washington	1.3	2.7	1.1	8.3	13.4	4.0	2.4
Wisconsin	3.3	2.9	1.2	3.8	11.2	6.2	4.5
Average	2.2	2.1	1.4	6.3	12.0	4.3	3.6

[1] Excluding those assigned to maintenance.

is wanted. If the ratio which exists between tables 1 and 2 is applied to all States, the figure becomes approximately 24,000 on a classification basis. If, on the other hand, the professional engineer concept is adhered to, the 18,034 figure is probably much too high; the actual number will depend on how the term "professional engineer" is defined.

This matter of definition is obviously an important one. Referring again to table 2, it is noted that 52 percent of the employees classified as engineers are neither civil engineering graduates nor registered professional engineers, the percentage varying from 34 to 63 among the six States. Also, only 35 percent of such employees are civil engineering graduages; only 31 percent are registered professional engineers; and only 18 percent are both civil engineering graduates and also registered professional engineers.

If an engineer is defined as a civil engineering graduate and/or a registered professional engineer, only 48 percent of those employees now classified as engineers could qualify according to table 2. Is this a reasonable definition, or does it do an injustice to the other 52 percent of the employees? Should these employees continue to be classified as engineers, or should they be reclassified and placed in high-grade engineering-aid classifications, which may not even exist at present? Granted that some of them may eventually attain registration, should our interest be directed toward potential or present qualifications?

In any event, table 2 presents some of the most important findings of the six-State study. It indicates that the engineers included by the States in the 1954 study were not reported on a uniform basis, and therefore raises a question as to the significance of any previously reported figure for the total number of engineers employed by the State highway departments. Also, by pointing out variations in the qualifications of employees classified as engineers, the tabulation demonstrates the need for a more exact definition of the term "engineer" and suggests a definition which might be usable; that is, a civil engineering degree and/or registration. Possibly this definition should be broadened to include the small number of mechanical, electrical, and other engineers engaged in State highway work.

Table 4.—Engineering personnel employed and number of engineering aids employed per engineer in six selected States

State	Engineering personnel employed: Engineering aids	Engineering personnel employed: Engineers	Engineering aids per engineer employed
Mississippi	459	216	2.1
Nebraska	237	235	1.0
Oregon	394	481	.8
Vermont	27	152	.2
Washington	376	627	.6
Wisconsin	606	403	1.5
Total	2,099	2,114	1.0

Now, what about the number of engineers employed per million dollars of capital outlay, on the basis of the information reported in the six-State study? Table 3 presents this information, according to the qualifications of the employees classified as engineers. This table was prepared by using the information presented in table 2, but excluding employees assigned to maintenance, with the capital outlays shown in table 1. The last column of table 1 is based on the 1954 study, while table 3 is based on the later six-State study.

According to table 3, the total number of employees classified as engineers per million dollars of capital outlay varies from 8.1 in Mississippi to 29.0 in Vermont. This is still a wide range, although not so extreme as that indicated by table 1. The principal differences are found in Mississippi and Washington, and are due to the substantially higher number of engineers reported for those States in table 2. Again referring to table 3, it should be noted that for the four States other than Mississippi and Vermont the total number of engineers per million dollars of capital outlay varies only from 11.1 to 13.4.

Similar variations exist for each of the several categories of engineers included in table 3. For those engineers who are both civil engineering graduates and registered, for example, the range is from 1.3 to 6.0; for all civil engineering graduates, the range is from 2.9 to 12.3. Although these ranges for the separate categories are less extreme on an absolute basis than is the range for total engineering employees, they are in most cases more extreme on a percentage basis. In all cases the upper extreme is represented by Vermont.

Since these rather wide variations still exist after the data reported by the several States have been put on a comparable basis, it is necessary to look further for an explanation. The next point of inquiry, then, is the number of engineering aids employed by the several State highway departments. Does the number of such aids vary directly or inversely with the number of engineers? If the latter, there is a possible explanation for the variations which exist with respect to the number of engineers employed per million dollars of capital outlay.

Relation of Engineering Aids to Engineers

There is no particular problem in defining the term "engineering aid", because the number of civil engineering graduates and/or registered engineers classified as engineering aids is insignificant. There is a problem of nomenclature, however, as to whether those employees who complement the engineers shall be called engineering aids, subprofessional employees, technicians, or something else. Since there is no obvious answer, they are called engineering aids here.

Table 4 shows the number of engineering aids employed and the number employed per engineer for each of the States included in the six-State study. It is noted, first, that the total number of engineering aids employed in all six States (2,099) is approximately the same as the number of engineers employed (2,114), so the ratio of engineering aids to engineers is 1.0. Incidentally, this ratio can be compared with a published overall ratio of one technician to 2.5 engineers for all fields of engineering and for all types of engineering endeavor.[4]

In the individual States, however, the ratio of engineering aids to engineers varies from 0.2 in Vermont to 2.1 in Mississippi. The significant fact here is that the low ratio exists in Vermont which has the highest number of engineers per million dollars of capital outlay, while the high ratio exists in Mississippi which has the lowest number of engineers per million dollars of capital outlay. Apparently there is some sort of an inverse relation between engineering aids and engineers.

This relation is demonstrated further by table 5, which shows the number of engineers and engineering aids employed per million dollars of capital outlay. Column 1 of this table is taken directly from table 3. Column 2 was obtained by combining data from tables 1 and 4; no correction was made for maintenance employees, because very few engineering aids are engaged in maintenance activities.

[4] *Engineers and technicians* (editorial), Engineering News-Record, vol. 155, No. 21, Nov. 24, 1955, p. 164.

Table 5.—Engineers and engineering aids employed per $1 million of capital outlay in six selected States

State	Engineering employees per $1 million of capital outlay[1]: Engineers	Engineering aids	Total
Mississippi	8.1	17.5	25.6
Nebraska	12.9	14.4	27.3
Oregon	11.1	9.8	20.9
Vermont	29.0	5.2	34.2
Washington	13.4	8.1	21.5
Wisconsin	11.2	18.1	29.3
Average	12.0	12.5	24.5

[1] See table 1 on p. 30 for capital expenditures.

Table 6.—Relative rank of six selected States according to capital expenditures, number of engineering employees, and number per $1 million of capital outlay [1]

State	Capital outlay	Number of engineers		Number of engineering aids		Number of engineers and engineering aids	
		Total	Per $1 million of capital outlay	Total	Per $1 million of capital outlay	Total	Per $1 million of capital outlay
Mississippi	4	5	6	2	2	4	4
Nebraska	5	4	3	5	3	5	3
Oregon	2	2	5	3	4	3	6
Vermont	6	6	1	6	6	6	1
Washington	1	1	2	4	5	2	5
Wisconsin	3	3	4	1	1	1	2

[1] The highest amount or ratio is ranked 1 in each case, the next highest 2, etc.

It is evident from table 5 that combining engineers and engineering aids reduces considerably the extreme variations in the number of engineering employees per million dollars of capital outlay. For engineers, the high figure is 358 percent of the low figure; for engineering aids, the high figure is 348 percent of the low. When the two are combined, however, the high figure is only 164 percent of the low figure.

It has been mentioned previously that program or capital outlay amounts may vary widely from year to year in a particular State, and in some States the number of engineering aids employed increases greatly during the construction season. In Nebraska, for example, the 1953 capital outlay was only $9.9 million, as compared with the 1954 figure of $16.5 million reported in table 1. In Wisconsin, the number of engineering aids employed practically doubles during the summer months. Thus, the ratios established cannot be considered as final or conclusive in any one instance, but do indicate a definite inverse relation between engineering aids and engineers.

This inverse relation explains at least partially the wide variations among the States with respect to the number of engineering employees per million dollars of capital outlay. Since the States use engineers and engineering aids in different proportions, a combination of the two is the best indication of engineering effort for a particular State. As previously mentioned, when States are compared on this combination basis, some of the extreme variations are eliminated.

It remains, then, to relate the number of engineers and engineering aids employed to both program characteristics and to management practices and procedures. Perhaps this analysis will explain further the variations among the States as to number of engineering employees per million dollars of capital outlay. In any event, it would be unrealistic to expect that these variations could be explained away entirely.

Program Characteristics

In relating the number of engineering employees to program characteristics, perhaps the most obvious feature to be considered is that of program amount. Other characteristics which can be analyzed include the relative amounts of rural and urban work, the relative amounts of "surfacing only" and all other work, and the average length of projects in each of the several work categories.

Table 6 shows the relative rankings of the six States selected for study with respect to program amounts and number of engineering employees. The rankings indicated in the first column are based on the program amounts reported in table 1, while those in the remaining columns are based on data in tables 2–5. Although not apparent at first glance, certain relations between program amounts and number of engineering employees are evident after some study of table 6.

The most direct relation is that between program amounts and total number of engineers; Washington, Oregon, Wisconsin, and Vermont rank 1, 2, 3, and 6, respectively, in each instance, while Mississippi and Nebraska rank 4 and 5 in one case and 5 and 4 in the other. Similar, but less direct relations exist between program amounts and total number of engineering aids and between program amounts and total number of engineers and engineering aids combined. These relations are not surprising, of course, since it is only reasonable that the number of engineering employees should increase with the size of the program.

As to relations between program amounts and number of engineering employees per million dollars of capital outlay, none is clearly evident from table 6. If any relations do exist, they are inverse relations, and this too is as it should be. It is logical that the number of engineering employees per million dollars of work should decrease, at least to some extent, with an increase in the amount of work.

The relations between total number of engineering employees and number per million dollars of capital outlay, as indicated by table 6, are quite surprising. For engineers alone and for engineers and engineering aids combined, these relations are not very definite; if they exist at all, they appear to be inverse. In the case of engineering aids, however, a direct and quite positive relation exists. No obvious explanation for this difference suggests itself, but again the variety of factors which may affect the ratios for the number of engineering employees per million dollars of capital outlay is emphasized.

In any event, table 6 establishes a direct relation between program amounts and number of engineering employees. As previously indicated, this relation is not unexpected, and in fact almost has to exist, since no relation or an inverse relation would be entirely illogical. The other relations indicated by table 6, if they exist at all, are not very positive, and probably are not significant.

Table 7 presents information on the relative amounts of rural and urban work and of "surfacing only" and all other construction work performed by the States. The program amounts on which this table is based are different from those indicated in table 1 and ranked in table 6, and in some cases the period covered is other than the 1954 calendar year. The program selected was one which could be conveniently analyzed by the State concerned, and generally the analysis is based on contracts awarded.

The theory here is, of course, that States doing a high percentage of urban work or a low percentage of "surfacing only" work will require more engineers than other States. The assumption is that urban projects and projects involving work other than surfacing or resurfacing only require more engineering effort. Whether this theory can be demonstrated depends on a comparison of table 7 with tables 2–5.

The rural percentage of total program costs varies from 75 in Washington to 89 in Mississippi, according to table 7. It follows then that the urban percentage varies from 25 in Washington to 11 in Mississippi. Theoretically, Washington should be using more and Mississippi fewer engineers than any other State included in the study. Table 5 indicates that Mississippi in fact uses fewer engineers per million dollars of capital outlay than any other State included in the study, and that Washington uses more than any other State except Vermont.

A comparison of the other data presented in table 7 with the information presented in earlier tables reveals no additional relations. In fact, such a comparison raises some questions about the direct relation which appears to exist between the urban percentage of total program costs and the number of engineers employed per million dollars of capital outlay. Washington, for example, does the greatest amount of urban work on a percentage cost basis, but also does the greatest amount of surfacing or resurfacing work on the same basis. Generally, it would appear that program costs are a more valid indication

Table 7.—Construction in rural areas and construction other than surfacing or resurfacing related to the total program

State	Construction in rural areas related to total program		Construction other than surfacing or resurfacing related to total program	
	Construction cost	Miles constructed	Construction cost	Miles constructed
	Percent	*Percent*	*Percent*	*Percent*
Mississippi	89	98	79	68
Nebraska	82	99	76	49
Oregon	88	94	85	73
Vermont	87	94	100	100
Washington	75	97	75	54
Wisconsin	80	96	85	59
Average	82	97	82	60

Table 8.—Average length of construction projects in six selected States

State	Average length of construction projects			
	Surfacing only		All other construction	
	Rural	Urban	Rural	Urban
	Miles	*Miles*	*Miles*	*Miles*
Mississippi	7.1	1.1	5.3	1.2
Nebraska	6.8	1.3	6.8	1.0
Oregon	2.8	1.4	1.5	1.2
Vermont	----	----	2.9	2.8
Washington	11.2	8.3	5.1	1.0
Wisconsin	5.0	.6	4.3	1.1
Average	6.5	2.0	3.8	1.1

of engineering effort than is program mileage, regardless of type of work.

The final program characteristic to be analyzed is that of project length. Table 8 presents information as to the average length of construction projects for both "surfacing only" and all other types of construction, and for rural and urban projects. Although these data are interesting, no relations between project length and number of engineering employees are evident.

With respect to program characteristics in general, there appears to be a direct and quite definite relation between program amount and total number of engineering employees, whether engineers alone, engineering aids alone, or both are considered together. Also, there appears to be a direct relation between the urban portion of total program costs and the number of engineers employed per million dollars of capital outlay, but a corresponding relation does not seem to exist in connection with engineering aids or engineers and engineering aids combined. Other relations either do not exist or are not apparent, possibly because of the relatively few States included in the study, and also because of certain intangibles such as climate, terrain, soil characteristics, and other factors which cannot be evaluated.

Management Practices and Procedures

Since this is primarily a classification study, a full-scale analysis of management practices and procedures was not attempted. Nevertheless, some attention was given to management practices and procedures in each State studied, and their possible effects on engineering manpower requirements were discussed with State personnel. Incidentally, it might be mentioned that classification is itself a management practice.

Of the six State highway departments included in the study, all but one are directed by commissions. In Mississippi, Oregon, and Vermont these commissions are 3-member part-time bodies, while in Washington the commission is a 5-member part-time body. In Wisconsin the commission is also a 3-member body, but serves on a full-time basis. The Nebraska Bureau of Highways is directed by a single executive, the State Engineer. Probably the type of directing organization has little effect on engineering manpower requirements in these six States.

In Oregon and in Washington one individual serves both as chief administrative officer and also as chief engineering officer. In each of the other four States, the chief administrative officer and the chief engineering officer are separate individuals. The commission chairman serves as chief administrative officer in Wisconsin, and in Nebraska the State Engineer serves as chief administrative officer, but in none of the other States does a member of the directing organization serve as either chief administrative or chief engineering officer. Again it seems that these differences have little effect on engineering manpower.

With respect to structural organization below the directing level, there are of course differences in the individual States, but all have field districts or divisions responsible to some extent for both construction and maintenance activities. All are decentralized to some degree, and all have the usual complement of central office bureaus. In spite of this overall similarity in structure, there are differences in operating methods which are significant in connection with a study of engineering manpower requirements.

In Mississippi, for example, few engineers but many engineering aids per million dollars of capital outlay are employed, and operations are decentralized to a considerable extent. Location surveys are made by field district personnel, and the project engineer lays a tentative grade on the project plan, which is used by the central office employees, if possible. Relatively inexpensive designs can be used because of the relatively light traffic in the State, and shortcuts are used in the design process itself. Standard plans are used for over 90 percent of all bridges, and bridge construction and maintenance are done by the regular construction and maintenance forces. Difficulty is experienced in hiring the higher grades of engineering personnel, but the lower grades are more readily available.

In Nebraska, where the number of engineering employees per million dollars of work is just slightly above the average for the six States included in the study, location is a central office function. Also, design has been a centralized function, but recently some of this work has been done in the field, and eventually the field will probably design everything except structures. All construction work, including Federal-aid secondary projects, is done to the same standards and specifications, and probably more inspecting is done than in most States. Also, State employees do most of the engineering work on Federal-aid secondary jobs. With respect to personnel, detailers are more critical than designers.

Oregon and Washington are alike in many ways, but present a marked contrast with respect to operating procedures. In Oregon, operations are largely on a centralized basis, and the field organization is somewhat rigid. In Washington, operations are decentralized to a considerable degree, and the field organization is quite flexible. Nevertheless, these two States have relatively few engineering employees per million dollars of capital outlay, and their records in this respect are the best of any of the six States studied, as is indicated by table 5.

Vermont employs more engineers and fewer engineering aids per million dollars of capital outlay than any of the other States included in the study, and there is no obvious explanation for the particularly high number of engineers employed. Probably a combination of factors, including an extreme climate, a difficult terrain, and a small program amount, is responsible. State highway operations are more centralized than in most other States, but the field districts do a considerable amount of engineering on State-aid work which is not reflected in the program amount. Also, many employees classed as engineers do work which is done by engineering aids in other States, although this is because of the classification system, rather than in spite of it. Incidentally, the State reports that because of this new classification system the shortage of engineers is no longer a problem.

Wisconsin uses relatively few engineers, but more engineering aids than any other State studied, per million dollars of capital outlay. More time and attention are given to management practices and procedures than in most other States, and the organization plan is one of decentralization with centralized controls. Planning is emphasized, and engineers are being used more and more in supervisory capacities rather than for operations. A trained corps of engineering aids or technicians is being developed, and these nonengineers are being substituted for engineers wherever possible. Expanded programs are being handled without any appreciable increase in the number of engineering employees.

It appears that in any particular State there are some management practices which promote overall efficiency and the efficient use of engineering personnel, and other practices which perhaps tend to be wasteful of personnel. Also, it might be noted that a procedure which promotes overall efficiency may at the same time appear to be somewhat wasteful of personnel. In any event, it is extremely difficult to correlate the ratio of engineering employees to capital outlays with particular management practices and procedures, and perhaps this ratio is determined primarily by other factors.

Wisconsin, for example, has emphasized the use of engineering aids, and its ratio of engineering aids to capital outlay is high. Vermont has adopted a classification plan which makes it possible for employees with only a practical background to attain relatively high-grade engineering classifications without taking examinations, and has the highest ratio of engineers to capital outlay of any State studied. Washington has accomplished the increased work resulting from a bond program without a proportionate increase in engineering personnel, while Oregon increased its engineering forces by only 40 percent over a 5-year period to handle a bond program which doubled the construction program. Probably, then, a major factor in the efficient use of engineering personnel is the necessity to get along with what is available.

The Shortage of Highway Engineers and How to Overcome It

OFFICE OF THE ASSISTANT TO THE COMMISSIONER BUREAU OF PUBLIC ROADS

Reported [1] by ROBLEY WINFREY, Chief, Personnel and Training Office

THE past 2 years have brought forth many serious discussions about the engineering manpower necessary to carry on a greatly increased program of capital outlay for highways. Current shortage of engineers has also been accorded its due attention. Month-by-month the highway departments are finding additional ways to do more highway work without hiring additional engineers. Highway department managements are tackling manpower needs with the same energy, alertness, and success that have always characterized their attack on the technical problems encountered in the effort to keep up with the ever-increasing demand for highway usage.

But what are the engineering needs? How can these needs be met successfully? Let's first look at highway engineering employment. What is it? How much do we have?

Engineers and Engineering Aids Employed

An engineer is what definition says he is. Each person, each civil service system, and each hiring organization has defined the engineer somewhat to fit local concepts and local needs. This lack of an accepted definition has prevented determining the number of engineers employed in the highway industry, public and private. The hiring of employees to assist the engineer under such titles as surveyors, draftsmen, computers, inspectors, and laboratory analysts is the primary reason for lack of uniformity in definition. For the purpose of this article these engineer assistants are grouped into one class and called engineering aids, sometimes known as subprofessionals, preprofessionals, nonprofessionals, and technicians.

The word "engineer" is used herein to refer to an employee or potential employee who is a registered professional engineer under the law of his State; eligible for such registration, but because of not being required to do so, has not applied for registration; a graduate at the level of bachelor of science or higher of an accredited college course in engineering; and those employees who are classified as professional engineers by the State highway department or under a local merit or civil service system. In the latter group, there will be found in certain States, employees classified as engineers who in other States are classified as engineering aids.

No census of highway employment exists on the basis of these or other known definitions; therefore, only estimates of the number of engineers employed are available. According to Campbell and Schureman (*3*) [2] the State highway departments in September 1954 were employing 18,034 engineers and had need for 3,990 more. Danner, in his committee report (*4*) indicated the employment of engineers by State highway departments to be 14,204 as of November 30, 1955, for 30 States. Prorating by the Campbell-Schureman data, Danner's total becomes 20,440 for the 48 States.

Lewis (*9*) reported further on the classification and employment of engineers in six States. The six-State study shows that the employment reported by Campbell and Schureman was controlled by different interpretations which were placed on the questionnaire sent out by the Highway Research Board as well as by differences in State classification. Another factor that has not been controlled is date of reporting. Employment varies considerably with seasons and with available funds, so these two studies are not directly comparable. Further, engineering aids or their equivalent were not reported in the Campbell-Schureman study and the extent they are included is unknown.[3]

In summary, the conclusion must be that the number of engineers and the number of engineering aids employed by the 48 State highway departments are not known. For purposes of later discussions, a total of 20,000 engineers and 20,000 engineering aids are used. Of the 20,000 engineers, 1,300 are assumed to be primarily maintenance engineers, leaving 18,700 engaged in duties pertaining to construction.

Lewis (*9*) reported for six States (Mississippi, Nebraska, Oregon, Vermont, Washington, and Wisconsin) that, exclusive of maintenance engineers, these States were employing 12 engineers per million dollars of capital outlay and that the ratio of engineers to engineering aids was 1 to 1. His report further shows that if the number of engineers per million dollars of construction is relatively high the number of engineering aids per million dollars of construction is relatively low. The reverse is also true.

Campbell and Shureman (*3*) found that the ratio of engineers per million dollars of construction varied from 2.0 to 28.2 State-to-State with a median ratio of 7.2. Since it is known that the data were not consistently reported by the States, the wide range of 2.0 to 28.2 and the median value of 7.2 are not of any determinable reliability.

The six States studied by Lewis were not chosen as being representative of the 48 States, but for other reasons associated with his objectives. But for purposes of illustration only, the assumption of 7.2 engineers per million dollars of construction outlay is used.

The 1955 construction expenditures by the State highway departments totaled about $2.5 billion, which at 7.2 engineers per million dollars indicates a requirement of 18,000 engineers.

For a greatly enlarged highway construction program the ratio of engineering employment to construction dollars could be reduced, and because of scarcity, will be reduced. But assuming the ratios of 7.2 engineers and 7.2 engineering aids for each million dollars of construction money available, an increase in the program of $2 billion annually would require an additional employment of 14,400 engineers and 14,400 engineering aids. Whether the increased program were handled wholly by the States, or by the States and consultants, the manpower requirements would be approximately the same. This requirement is 80 percent of the current employment in the engineering operations. The 14,400 additional engineers are just not available, so how can the program be supplied with adequate engineering services? The following analysis presents an interesting five-way approach.

Meeting the Manpower Requirement

The total engineering services can be supplied for a highway construction program at an increased rate of $2 billion a year. Although the facts are not available from which a de-

[1] This article was presented at the Ninth Northwest Conference on Road Building, University of Washington, Seattle, Feb. 1956.

[2] Italic numbers in parentheses refer to the list of references on page 36.

[3] The Highway Research Board is undertaking a census of the State highway department engineering employees as of March 1, 1956. Results should be available by July 1.

tailed breakdown can be presented, the following plan is both possible and reasonable.

First, adjust present employment procedures, operations, management policies, and assignments to those selected from the 48 States that have been successful in operating with the least amount of engineering services.

Second, shift as many duties as possible from engineers to engineering aids, and from engineers and engineering aids to fiscal, clerical, and administrative employees.

Third, adjust personnel management policies and employee relations to effect measures which will reduce the number of resignations and which will increase general productivity.

Fourth, operate in-service training and educational programs as a means of increasing quantity and quality of production of employees and of upgrading their classification.

Fifth, plan and execute an organized program of recruiting manpower and of selling highway employment to college and high school graduates who now seek other employment. Also, organize to hire from the large number of college students who drop out of college short of graduation.

There is not opportunity today to go into detail of what can be accomplished under step 1. Reports by Campbell (*2*) and Schureman (*10*) mention the following possibilities which have been achieved by one or more States:

1. Use aerial photographs and photogrammetric methods in location studies and mapping (50 to 80 percent saving in highway department manpower).
2. Identify soil types from aerial surveys.
3. Compute coordinates, error of closure, areas, and other survey calculations by automatic computing machines.
4. Adopt new surveying instruments of improved design. A new self-leveling level will cut time of leveling by 50 percent.
5. Adopt a State coordinate system of survey control.
6. Use standard designs for elements of the overall plans for highways, small structures, and bridges.
7. Use high-speed electronic computers in stress analysis.
8. Eliminate duplicated and unnecessary detail on construction plans, and use supplementary sheets for standardized items.
9. Use typing and acetate sheets instead of hand lettering on plans.
10. Use pencil drawings rather than "inked tracings" and use photographic methods of reproduction instead of blueprinting.
11. Compute earthwork quantities by business machines rather than by hand plotting.
12. Compute earthwork quantities from aerial photographs.
13. Centralize computations, estimating, pricing, and analysis of bids.
14. Increase length of roadway projects per contract.
15. Save engineers by increasing the number of survey parties supervised by one engineer and increase the number of construction projects handled by a resident engineer.
16. Streamline the whole process of highway design and construction to eliminate duplicated effort, unessential checking and reviews, and assign as many operations as possible to workers skilled in special operations.
17. Use mobile communication systems for field control.
18. Use many of the 1,500 separate items collected by Campbell (*2*).
19. Adopt many other items yet in experimental stages and concentrate on the development of new ideas.

By achieving the maximum improvement in the overall total engineering processes, the number of engineers required per million dollars of construction could be greatly reduced for the proposed total program.

In the second step, many of the duties now performed by engineers can be assigned to engineering aids. In this process, suitable training will need to be given the engineering aids as mentioned in step 4. The potential saving of the manpower of engineers by this process should result in the employment ratio of 1 engineer to 2 engineering aids. In another 10 years a ratio of 1 to 3 might be achieved. Certainly, the State highway department engineers could quickly devise work processes, and so arrange the assignment of duties that each engineer could direct the work of two aids.

The third and fourth steps, personnel management and in-service training, should be combined to effect an overall increase in productivity and to permit a reduction of at least 10 percent in engineering services per million dollars of construction.

Engineering Services Required for an Accelerated Program

If all the new devices, methods, and procedures known to be available were used and the best personnel management practices were followed, engineering services for construction could be reduced from 7.2 engineers and 7.2 engineering aids to 5 engineers and 10 engineering aids per million dollars of construction.

Assuming the use of the ratio of 5 engineers and 10 engineering aids for the new construction program of $2 billion in addition to the current State highway department program of about $2.5 billion, the total requirement for $4.5 billion would be 22,500 engineers and 45,000 engineering aids. These two estimates compare with the previous estimate of 18,700 engineers and 20,000 engineering aids presently employed by State highway departments. The necessary increases would be 3,800 engineers and 25,000 engineering aids. Recruiting these numbers should be possible under a planned program and with determination to do so.

This analysis results in an estimate of additional engineers far less than the number many highway engineers have in mind. The actual figures must await a reliable census of current employment. However, strong support must be accorded to the basic principle proposed—the number of engineers required per million dollars of construction can be reduced materially from the existing ratio (whatever it may be) by applying the new know-how. And if the new enlarged program is to be achieved, the ratio *must* be cut about 50 percent.

Recruiting for Additional Manpower

The additional personnel required for the increased highway construction program should be obtainable from the following sources and by the methods indicated. An important factor is that at least 3 years would be available before the full number of engineers would be needed.

1. From increased numbers of graduating engineers, brought on through an upward trend in enrollment and by a more active recruiting program, some 3,000 engineers could be hired in the next 3 years. In 1955 the engineering colleges graduated 3,868 civil engineers with bachelor degrees. In 1958 the number should increase to about 5,500. In 1955 the State highway departments hired about 550 graduates. By organized and determined recruiting, certainly an average of 1,000 a year is possible from 1956 to 1958.
2. By recruiting directly for the high school graduate under a planned program, a total yearly employment of 15,000 could be achieved. In 1954–55 the Nation's high schools graduated 1,399,300 boys and girls.
3. Close attention should also be directed to the hiring of engineering students who do not complete their college program. Many colleges graduate only 30 to 50 percent of those students who enroll as freshmen.
4. Employment can be greatly increased by bringing into highway employment, engineers, technicians, aids, and other types of trained personnel who can easily adapt their training and experience to highways. Branches other than civil engineering should be tapped for available employees.
5. When the total employment of civil engineers by all levels of government and private firms is considered, there is a large employment to draw upon. Within these other government employments it will be possible to effect many of the same savings of manpower as suggested for the State highway departments. Adoption of such improved methods should make it possible to release several hundred engineers for highway work without unduly handicapping normal operations of the other agencies and firms.
6. By utilizing services of private engineering firms for the most difficult and unusual type of facilities, by contracting out all possible nonengineering services but including aerial surveying, map making, printing of plans, and special rights-of-way functions, the equivalent of thousands of employees can be added to the States' services.
7. Through improved personnel management, the rate of resignation can be reduced materially. The rate of resignation for civil engineering graduates as experienced by 26 States was reported (*12*) to be 48.8 percent in the first 14 months for the 1952 class and 19.0 percent in 2 months for the 1953 class. Further, employees by better placement can materially increase their production.
8. Much can be gained by improving employee utilization through research and experimentation into human relations and human productivity. Where does it get the highway industry to spend millions of dollars each year on research on use of materials,

Table 1.—Application of the ratio of one engineer to two engineering aids to the employment practices in three States following an 80-percent increase in funds over the 1955 construction program

	Employment in 1955 with a $50-million construction program			Employment with a $90-million construction program [1]			Change in employment with increase in program		
	State A	State B	State C	State A	State B	State C	State A	State B	State C
Number of engineers employed	700	500	350	450	450	450	−250	−50	+100
Number of engineering aids employed	400	500	700	900	900	900	+500	+400	+200
Engineering aids per engineer	0.57	1.00	2.00	2.00	2.00	2.00	-----	-----	-----
Engineers per $1 million of construction	14	10	7	5	5	5	−9	−5	−2
Engineering aids per $1 million of construction	8	10	14	10	10	10	+2	0	−4
Total engineering employees per $1 million of construction	22	20	21	15	15	15	−7	−5	−6

[1] Based on a $40-million increase in the 1955 construction program for three typical States, and an employment rate of 5 engineers and 10 engineering aids per million dollars of construction.

machines, and money and not a dollar on how to understand those human factors which in the end control and utilize the product of such physical research? Research on how to use the power of man can greatly alter our concept and utilization of manpower. With such new concept we should not hesitate to embark on a program of construction double the current rate of expenditure.

9. Operation of essential training programs for both college civil engineering graduates and engineering aids should be considered. See references (*8*), (*12*), (*13*), and others, for suggested programs and States now operating successful programs. Notable success in the training of high school graduates is being achieved by Connecticut, Iowa, Michigan, Nebraska, and Wisconsin (*13*). Many States have cooperative arrangements with colleges for the alternate college-work plan by which one group of college students is exchanged with a second group at the highway department on a scheduled basis.

10. Educational programs and in-service training programs can be used as a means of preparing present employees for upgrading and qualifying them for professional positions. This plan should make available a considerable number of engineers and the vacancies created by their promotions can be filled by younger and less experienced new employees.

There is no basis for making an estimate of the overall increase in employment of engineers and engineering aids that would result by full application of these 10 methods. Over a 3-year period, however, employment certainly would approach the estimated total need of 22,500 engineers and 45,000 engineering aids.

Ratio of One Engineer to Two Engineering Aids

An application of the plan to typical State conditions is shown in table 1. For a total national increase in the construction program of $2 billion each State (A, B, and C) might receive an increase of $40 million annually. The total program for each State would then be $90 million a year. At the rate of 5 engineers and 10 engineering aids per million dollars, each State (A, B, and C) would then require 450 engineers and 900 engineering aids. The resulting changes in employment are shown in the last three columns of the table.

It is not likely that States A and B would decrease the number of engineers employed when practically doubling their construction program. But the indicated increase in the number of engineering aids could be expected. In view of the discussion at the beginning of this article about the census and classification of engineering employment, it can be said that States A and B may have a large number of aids classified as engineers in comparison with State C. But the three States have 22, 20, and 21 engineering employees per million dollars of construction funds. The goal of 15 total—5 engineers and 10 aids—calls for a reduction of 7, 5, and 6, respectively.

Certainly such reduction in the ratio of engineering employment is possible. By adopting all that is currently known about how to conserve engineering manpower and all that can be discovered in the next 3 years, this proposed reduction in ratio (increase in productivity per employee) is reasonable, practical, and possible. In fact, should the Congress authorize the funds for an accelerated program such adjustments in the utilization of engineering services will come about of necessity.

Highway engineers have always successfully met their technical challenges. We can now have confidence that they will again meet their technical challenge and their human challenge as well.

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Bibliography of Highway Planning Reports (1950). 30 cents.
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Federal Legislation and Regulations Relating to Highway Construction (1948). Out of print.
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General Location of the National System of Interstate Highways, Including All Additional Routes at Urban Areas Designated in September 1955. 55 cents.
Highway Bond Calculations (1936). 10 cents.
Highway Bridge Location No. 1486D (1927). 15 cents.
Highway Capacity Manual (1950). $1.00.
Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
Highway Practice in the United States of America (1949). 75 cents.
Highway Statistics (annual):
1945 (out of print). 1949, 55 cents. 1953, $1.00.
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1947, 45 cents. 1951, 60 cents.
1948, 65 cents. 1952, 75 cents.
Highway Statistics, Summary to 1945. 40 cents.
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Manual on Uniform Traffic Control Devices for Streets and Highways (1948) *(including 1954 revisions supplement)*. $1.00.
Revisions to the Manual on Uniform Traffic Control Devices for Streets and Highways (1954). *Separate*, 15 cents.

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Mathematical Theory of Vibration in Suspension Bridges (1950). $1.25.
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Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.
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Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents.
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Transition Curves for Highways (1940). $1.75.

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State Transportation Map series (available for 39 States). Uniform sheets 26 by 36 inches, scale 1 inch equals 4 miles. Shows in colors Federal-aid and State highways with surface types, principal connecting roads, railroads, airports, waterways, National and State forests, parks, and other reservations Prices and number of sheets for each State vary—see Superintendent of Documents price list 53.
United States System of Numbered Highways. 28 by 42 inches, scale 1 inch equals 78 miles. 20 cents.

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Bibliography on Automobile Parking in the United States (1946).
Bibliography on Highway Lighting (1937).
Bibliography on Highway Safety (1938).
Bibliography on Land Acquisition for Public Roads (1947).
Bibliography on Roadside Control (1949).
Express Highways in the United States: a Bibliography (1945).
Indexes to PUBLIC ROADS, volumes 17–19 and 23.
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STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF APRIL 30, 1956

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$3,608	$18,367	$9,932	304.0	$8,876	$5,015	61.6	$43,015	$22,559	642.5	$70,258	$37,506	1,008.1
Arizona	1,530	6,282	4,722	104.0	3,741	2,867	46.2	10,557	7,867	106.8	20,580	15,456	257.0
Arkansas	7,950	16,787	8,414	527.8	6,372	3,343	56.6	22,561	11,589	471.9	45,720	23,346	1,056.3
California	3,787	23,345	12,645	219.7	15,481	8,187	17.9	155,393	79,666	295.4	194,219	100,498	533.0
Colorado	15,893	6,265	3,528	84.6	1,993	1,156	23.0	17,562	9,440	190.5	25,820	14,124	298.1
Connecticut	20,334	3,685	1,905	7.6	1,778	947	4.2	12,338	6,249	17.3	17,801	9,101	29.1
Delaware	3,999	3,825	1,922	40.5	1,534	792	21.1	6,170	3,089	50.7	11,529	5,803	112.3
Florida	6,498	11,753	6,356	141.1	11,758	6,191	47.6	36,603	18,753	369.5	60,114	31,300	558.2
Georgia	20,962	20,683	10,748	319.9	8,925	4,319	105.9	45,828	21,660	743.6	75,436	36,727	1,169.4
Idaho	6,071	5,455	3,476	87.9	4,154	2,685	68.1	12,352	8,078	149.1	21,961	14,239	305.1
Illinois	12,041	38,797	20,596	692.9	21,090	11,455	84.6	95,943	52,201	479.6	155,830	84,252	1,257.1
Indiana	23,127	23,775	12,572	177.5	13,368	6,896	147.4	45,096	24,800	144.1	82,239	44,268	469.0
Iowa	4,569	22,265	12,733	1,006.8	8,936	4,924	117.5	27,670	14,865	778.8	58,871	32,522	1,903.1
Kansas	6,838	15,069	7,827	906.1	9,645	5,115	179.5	22,238	11,402	816.1	46,952	24,344	1,901.7
Kentucky	12,697	8,270	4,169	183.9	1,906	1,140	4.8	40,812	21,649	587.0	50,988	26,958	775.7
Louisiana	8,606	14,589	7,302	86.2	3,302	1,658	1.6	48,236	23,159	482.8	66,127	32,119	570.6
Maine	3,089	11,265	5,855	93.6	86	86		15,895	8,186	107.9	27,246	14,127	201.5
Maryland	4,968	22,595	11,722	143.4	12,684	5,632	16.4	20,774	10,835	71.2	56,053	28,189	231.0
Massachusetts	13,521	12,353	6,167	18.5	13,556	7,342	8.9	41,460	20,041	62.2	67,369	33,550	89.6
Michigan	8,196	36,026	18,194	670.8	20,973	11,253	115.4	65,345	33,704	438.5	122,344	63,151	1,224.7
Minnesota	5,748	18,531	9,777	1,000.5	10,235	5,811	203.1	35,128	18,504	946.0	63,894	34,092	2,149.6
Mississippi	10,236	11,083	5,430	472.6	6,241	3,498	171.7	27,212	13,937	713.1	44,536	22,865	1,357.4
Missouri	3,548	34,826	17,453	1,457.2	1,121	557	1.3	79,657	41,732	1,196.5	115,604	59,742	2,655.0
Montana	12,693	10,999	6,644	201.9	7,358	4,500	137.5	24,903	15,540	432.8	43,260	26,684	772.2
Nebraska	14,170	11,027	5,878	318.8	4,869	2,590	101.6	32,889	17,318	965.2	48,785	25,786	1,385.6
Nevada	10,485	1,225	1,023	24.1	2,690	2,282	27.3	8,535	7,199	174.0	12,450	10,504	225.4
New Hampshire	5,746	1,938	1,175	10.9	1,724	860	7.9	8,387	4,321	53.1	12,049	6,356	71.9
New Jersey	21,293	10,364	4,785	54.6	6,361	3,297	11.8	33,270	15,433	43.6	49,995	23,515	110.0
New Mexico	5,852	3,335	2,133	40.5	4,121	2,621	80.9	12,260	8,082	208.3	19,716	12,836	329.7
New York	40,997	35,680	19,307	95.9	54,805	27,861	121.9	200,346	93,455	253.2	290,831	140,623	471.0
North Carolina	8,790	23,649	11,612	508.1	2,425	1,153	32.4	55,463	27,351	667.9	81,537	40,116	1,208.4
North Dakota	4,057	13,132	6,755	1,365.9	10,230	5,223	645.7	9,852	5,059	541.7	33,214	17,037	2,553.3
Ohio	16,658	54,541	28,425	226.6	11,497	6,280	30.1	81,889	40,391	123.0	147,927	75,096	379.7
Oklahoma	12,664	16,595	8,379	340.8	10,526	5,375	130.4	38,312	20,097	359.2	65,433	33,851	830.4
Oregon	3,607	2,400	1,410	35.3	2,870	1,758	27.9	26,228	16,129	255.1	31,498	19,297	318.3
Pennsylvania	31,380	10,913	5,807	31.6	44,399	20,863	38.5	103,446	53,129	368.0	158,758	79,799	438.1
Rhode Island	1,401	1,910	955	5.7	3,828	1,919	8.4	19,557	10,092	28.9	25,295	12,966	43.0
South Carolina	8,981	18,784	10,142	376.4	897	502	9.1	20,404	10,644	403.4	40,085	21,288	788.9
South Dakota	1,724	20,217	11,663	749.0	7,689	4,499	263.0	13,578	7,743	570.9	41,484	23,905	1,582.9
Tennessee	16,534	17,061	8,535	335.8	4,394	2,200	27.5	47,137	21,730	558.0	68,592	32,465	921.3
Texas	11,952	19,438	10,281	439.0	27,297	14,372	254.3	120,546	63,565	1,853.3	167,281	88,218	2,546.6
Utah	696	9,193	6,874	200.3	1,287	982	11.0	13,307	9,969	130.3	23,787	17,825	341.6
Vermont	3,801	3,041	1,520	32.5	113	59		10,252	5,298	93.5	13,406	6,877	126.0
Virginia	11,516	21,089	11,078	350.7	4,334	2,220	31.3	30,716	15,252	313.9	56,139	28,550	695.9
Washington	4,069	20,714	11,600	238.6	8,286	4,804	151.8	22,286	11,853	179.1	51,286	28,257	569.5
West Virginia	15,621	9,707	5,057	33.9	3,607	1,915	10.2	17,478	8,797	61.2	30,792	15,769	105.3
Wisconsin	8,767	19,744	9,971	275.6	9,203	5,014	79.7	51,721	25,391	503.5	80,668	40,376	858.8
Wyoming	658	7,431	4,918	107.8	1,257	809	25.3	16,997	11,133	337.8	25,685	16,860	470.9
Hawaii	3,792	3,651	1,805	10.1	3,723	1,834	3.5	4,251	1,888	5.8	11,625	5,527	19.4
District of Columbia	9,751	2,177	1,076	1.4	1,797	883	1.5	9,909	4,455	2.6	13,883	6,414	5.5
Puerto Rico	6,782	11,208	5,446	34.6				18,034	8,292	48.0	29,242	13,738	82.6
TOTAL	502,253	767,054	407,699	15,193.5	429,342	227,544	3,774.9	1,979,798	1,023,571	19,396.4	3,176,194	1,658,814	38,364.8